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FASOR II: CORRELATIVE BIOLOGICAL AND ACOUSTICAL STUDIES IN THE NORTH PACIFIC OCEAN

Peter F. Seligman, et al

Naval Undersea Center
San Diego, California

January 1975

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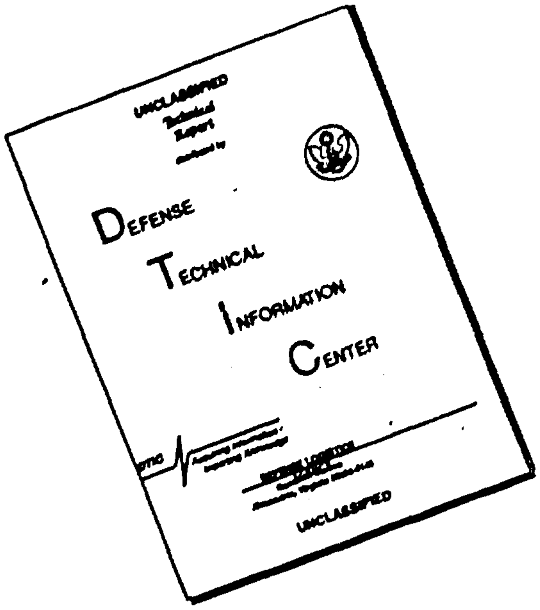

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FASOR II: CORRELATIVE BIOLOGICAL AND ACOUSTICAL STUDIES IN THE NORTH PACIFIC OCEAN

by

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January 1975

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ADMINISTRATIVE INFORMATION

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

An experimental analysis of acoustic and biological measurements collected during a Forward Area Sonar Research (FASOR) Cruise in the North Pacific Ocean (Feb. through Jul. 1966) is presented. Specifically, the relationship among biological samples, acoustical phenomena of echo groups, 12 kHz scattering layers, and 3 and 12 kHz volume scattering measurements, and water mass characteristics is investigated. Studies delineate eight oceanic regions as distinctive in biological and acoustic character (signature). Within these regions the following general results are derived

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20 ABSTRACT (Continued)

Large echo groups (LEGs), principally concentrated in nearshore areas, are patchy, variably distributed and, except for the Sea of Japan, have a higher day than night concentration.
Scattering layers from 12 kHz records are present in all areas except the Sea of Japan. Number of layers, depths, and vertical migratory patterns tend to vary between areas.
Column strength values at 3 and 12 kHz are maximal in the northeast Pacific and South China Sea. The concentration of echo groups and the intensity of 12 kHz volume scattering are inversely related.
The concentration of Mesopelagic fish is positively correlated with volume scattering. The concentration and composition of catches varies between oceanic regions, possibly because of the distinctive physical characteristics of the respective water masses.

SUMMARY

PROBLEM

Obtain acoustic measurements and biological samples from a wide geographic area in the North Pacific Ocean. Investigate the relationship between the water environment and its related biological community. Select for analysis oceanic regions based on their distinctive physically defined water types. Summarize the biological acoustical characteristics (signatures) of selected regions, each with physically defined water mass characteristics, in the North Pacific Ocean to help formulate predictive reverberation models.

RESULTS

Data collected from northern Pacific waters indicate a relationship exists among the biological, acoustical, and physical characteristics of water masses. Analysis of echo groups, observed scattering layers, column scattering strength measurements, and captured organisms defines signatures (unique biological and acoustic character) for eight geographical areas: 1. Northeast Pacific (Transitional Domain and Central Subarctic Domain), 2. Northwest Pacific (Western Subarctic Domain), 3. Sea of Okhotsk, 4. Western Pacific, 5. East Coast of Japan, 6. Sea of Japan, 7. East China Sea, and 8. South China Sea. The following general conclusions emerge.

- Large echo groups (LEGs) are concentrated in, but not limited to, near-shore areas. LEGs tend to have a patchy, highly variable distribution and, except for the Sea of Japan, show higher day than night concentrations.
- Scattering layers from 12 kHz echo sounder records appear in all areas except the Sea of Japan. Number of layers, depths, and vertical migratory patterns tend to vary with water mass characteristics.
- Scattering measurements of 3 and 12 kHz column strength values are mostly moderate (−50 to −65 dB) with maximum values appearing in the Central Subarctic Domain (Northeast Pacific) and the South China Sea. The concentration of echo groups and the intensity of 12 kHz volume scattering appear to be inversely related.
- Volume scattering is inversely related to plankton concentration, particularly in the Sea of Japan and the Sea of Okhotsk where scattering levels are low and zooplankton concentrations are high. Mesopelagic fish concentration exhibits a positive correlation with volume scattering. Both plankton and fish are found to vary between water masses having distinctive biological/acoustical characteristics.

RECOMMENDATIONS

1. Formulate predictive reverberation models from acoustic reverberation studies based on known and measured mesopelagic fish morphology and population characteristics.

2. Study further the interference of echo groups on the operations of various sonar and acoustic systems and define causative organisms.

3. Continue intensive studies of biological-acoustical interactions within physically defined sea areas to estimate the effect of seasonal variability on reverberation models.

CONTENTS

INTRODUCTION

Knowledge of the oceanic environment and how it relates to marine organisms is of vital importance to the Navy because it constitutes the background against which modern high powered sonar must detect echoes of interest.[1,2] The significance of biological organisms as a major cause of sound scattering and reverberation in the ocean volume has been documented by several investigators.[3-8] Early investigations described the relationship between planktonic organisms and the deep scattering layer (DSL).[3,4] Later, the relationship between fish and acoustic scattering was emphasized.[5,6] In 1957 it was suggested that swimbladders in certain fish might be largely responsible for measured sonic scattering.[7]

Measures of acoustic scattering have been extended to include geographical variations in volume reverberation and show that the intensity of volume scattering roughly correlates with latitude, primary productivity, and zooplankton standing stock as estimated by net haul catch volumes.[9] Further, nearly continuous 12 kHz echo sounder recordings have been analyzed to describe discrete acoustic targets called large echo groups (LEGs), which greatly increase reverberation levels. Although reverberation has been acknowledged as a problem affecting sonar operation for some time, not enough has been known in the past about the amount and variation of biologically caused acoustic scattering in order to formulate reverberation models that could reliably predict the spatial and temporal variability for specific regional areas.

The purpose of this report is to extend the existing data base of knowledge and document the general relationship that exists among the biological and acoustical phenomena of LEG distribution and scattering layer patterns and the physical characteristics of water masses. Experimental results are shown graphically as 3 and 12 kHz volume scattering strength versus depth, as well as column strength values, and mean LEG density patterns with comparisons made from day to night for specific regional areas in the North Pacific Ocean.

Data presented here are derived from the second in a series of expeditions undertaken in 1964 by scientists at NELC (now NUC) to obtain acoustic and biological data pertinent to the improved prediction of sonar performance. The platform USNS Charles H. Davis (AGOR 5) was used for the entire FASOR II (Forward Area SOnar Research Program) cruise which extended from the transitional domain of the northeast Pacific to the marginal East and South China Seas of the western Pacific Basin, as illustrated in Figure 1.

The eight geographical areas distinguished were delineated on the basis of their distinctive oceanographic characteristics observed on the cruise. Data were collected at twenty-one stations designated as A through U, respectively. For clarity these stations are identified with their physically defined oceanic region in Table 1.

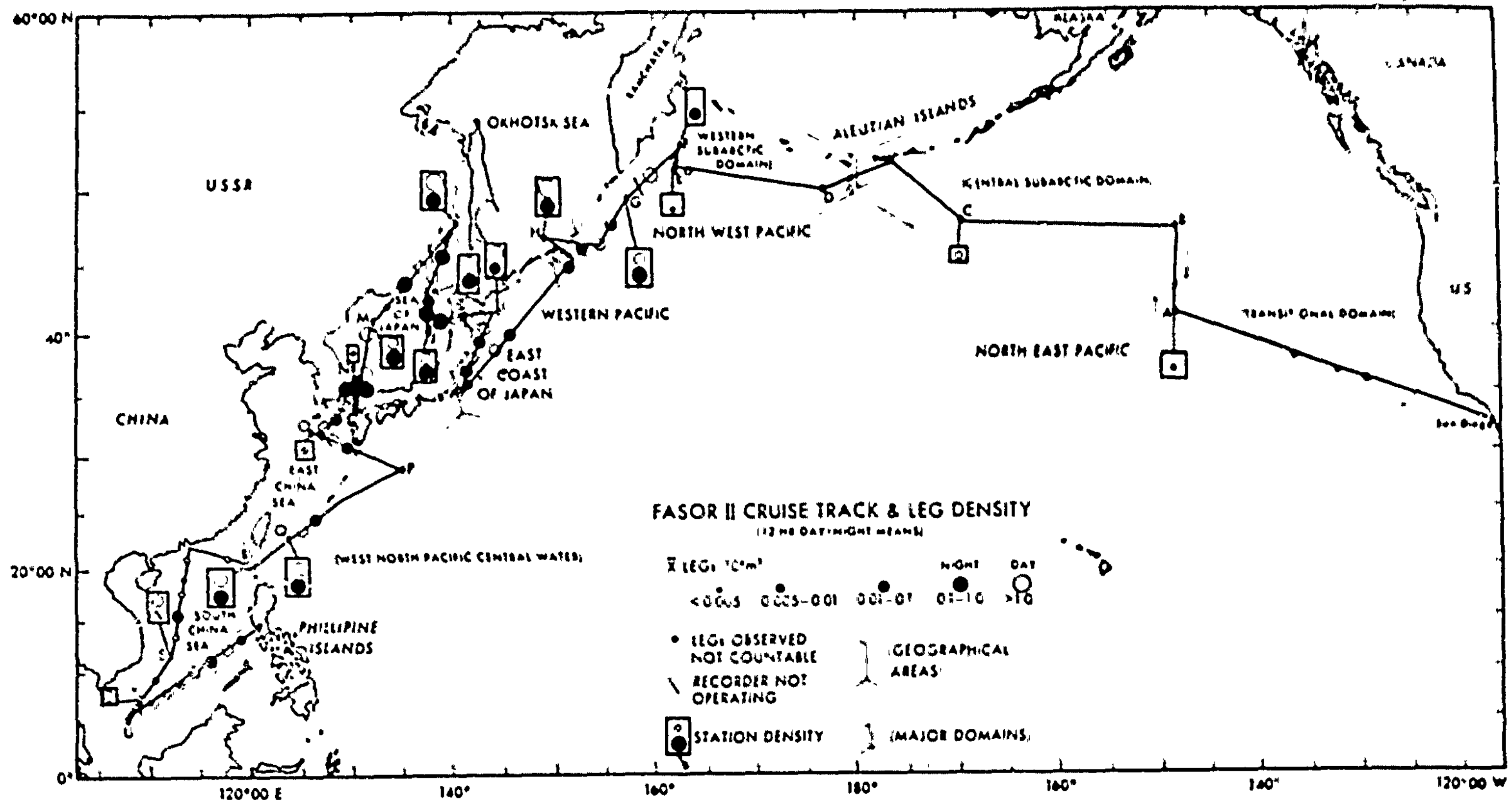

Figure 1 FASOR II cruise track, station locations, and large echo group (LEG) density

Table 1. Location of Stations Within Physically Defined Oceanic Regions

Station Designation	(Oceanic Region)	Geographical Location of Cruise Transit within Oceanic Region (Degrees)	Date of Cruise Transit
	1. Northeast Pacific		
A	• Transitional Domain	35°N, 125°W to 43°23'N, 147°57'W	2/3/66 to 2/11/66
B, C	• Central Subarctic Domain	43°23'N, 147°57'W to 50°30'N, 178°W	2/12/66 to 2/27/66
D, E, F, G	2. Northwest Pacific		2/28/66 to 3/11/66
	• Western Subarctic Domain	50°48'N, 180° to 45°30'N, 153°30'E	3/12/66 to 3/15/66
H	3. Sea of Okhotsk	45°39'N, 152°30'E to 45°47'N, 150°46'E	3/16/66 to 4/2/66
	4. Western Pacific . No samples taken	45°47'N, 150°46'E to 35°47'N, 141°13'E	
I	5. East Coast of Japan	35°47'N, 141°13'E to 41°39'N, 141°28'E	4/3/66 to 4/8/66
J, K, L, M, N	6. Sea of Japan	41°31'N, 141°28'E to 33°30'N, 129°21'E	4/8/66 to 4/29/66
O, P, Q	7. East China Sea	33°30'N, 129°21'E to 20°46'N, 125°15'E	4/30/66 to 5/12/66
R, S, T, U	8. South China Sea	20°46'N, 120°15'E to Subic Bay, P.I.	5/13/66 to 6/3/66

DATA ACQUISITION

FASOR II data were collected between 2 February and 6 June 1966. Standard oceanographic measurements, including temperature and salinity determinations, were taken at each station and continuous 12 kHz echo-sounder recordings were made over most of the cruise track.

Volume reverberation measurements were made with directional transducers at frequencies of 3.0 and 12.0 kHz. These highly directional sources were oriented vertically downward and were positioned about 8 meters, or 25 feet, below the sea surface; each transducer functioned as both source and receiver. The returned signals, after amplification and filtering, were recorded on magnetic tape and displayed as an analog record. Amplitude measurements on this record supplied the basic data from which the volume-scattering strength information was calculated. A description of receiving equipment and data reduction procedures has been previously reported.[9, 11, 12]

Biological samples were taken with a modified Tucker Trawl[13] that had a two-meter per side square mouth and was constructed of two types of netting: a 1.1 centimeter (stretched) mesh Marlon, 5 meters long, in the forward position and a 0.3 millimeter mesh Nytex plankton netting, a cone 2 meters long with a mouth diameter of 0.5 meters, in the after position. The trawl terminated in a stainless steel cod-end bucket.

Standard oblique net hauls were made between the surface and approximately 225 meters at deep-water stations and between the surface and bottom at the shallow stations,

O, I and V. Typically, two hauls were made per station as near midday or midnight as possible. During each haul, net depth was determined by a Benthos model 1040 Depth Telemetering Pinger and was read aboard ship from a Westrex Mark 10-A Precision Depth Recorder. Because of the varying water depths and types of hauls sampled, maximum haul depths ranged between 69 and 335 meters. All hauls were made with the ship towing at a speed of about 1.5 knots, or 46 meters per minute.

The volume of water filtered is the product of the trawl mouth area (4 square meters) and the length of the trawl's path through the water on a given haul. This determined quantity was used to compute the concentrations of fishes and primary and secondary plankton captured in each haul. Although the bulk of the plankton was undoubtedly sampled by the latter portion of the trawl, the efficiency of this Nytex cone is unknown. Thus, actual concentrations of the smaller secondary plankton were probably greater than is reported here. The data are considered valid, however, for relative comparisons between stations.

The depth, frequency of occurrence and apparent strength of scattering layers were analyzed directly from echograms recorded on the precision depth recorder. A hull-mounted 12 kHz transducer powered by a T. H. Gifft Co. sonar transceiver was used to provide continuous echogram recordings. Each 12-hour period was represented with measurements as close to midday and midnight as possible.

Although echo sounder records are not available for the entire cruise track, a reasonably complete suite of recordings of scattering layers and spurious acoustic targets, defined by Dr. E. G. Barham as Large Echo Groups (LEGs), was obtained. LEGs were counted in a time-depth relationship directly from the 12 kHz echo sounder records and were summarized as numbers of LEGs per million cubic meters of insonified water for 12-hour day and night segments of the cruise.

The volume of insonified water was determined by assuming a 30-degree functional sound cone for the transducer. The lower limit considered was 240 fathoms, or 439 meters. Ship speed was known and thus the distance the ship traveled per hour was transformed into a volume searched per hour by calculating a wedge-shaped segment of insonified water having a depth of 240 fathoms, an apical angle of 30 degrees, and a length equal to that of the ship's track. The validity of these assumptions used to estimate such a volume searched has previously been investigated.[14]

Correlations between various biological and acoustical parameters were derived from both individual station data and geographical-physical areal mean values (data from groups of stations). The Pearson product-moment correlation coefficients were calculated and significance probabilities were determined from these values.

AREAS SURVEYED

The geographical areas which make up the distinctive oceanic regions were chosen on the basis of both historical and collected oceanographic data. The physical characteristics of the water in relation to water mass and geographical area for each region is discussed below.

1. NORTHEAST PACIFIC   Stations A, B, and C; data collected from 2 Feb to 27 Feb 1966.

The two oceanographic areas traversed in the Northeast Pacific Basin were the Transitional Domain and the Central Subarctic Domain. These domains have been defined as areas of consistent oceanographic structure and physical behavior.[15]

- Transitional Domain   Station A: data collected from 3 Feb to 11 Feb.

  The Transitional Domain extends westward from approximately 125°W to 145°W and northward to the Subarctic boundary (approx. 45°N). Near-surface temperatures are above 7°C during the winter and surface salinities may be expected to exceed 33.2 parts/thousand (ppt) in this domain; the respective values observed on station A were 10.3°C and 33.5 ppt. Salinity reached 34 ppt at 150 meters. The thermocline was weakly developed and the mixed layer extended to 100 meters. Temperatures gradually decreased to 3.23°C at 1000 meters.

- Central Subarctic Domain   Stations B and C: data collected from 12 Feb to 27 Feb.

  The Central Subarctic Domain extending from 43°23'N, 147°57'W to 50°30'N, 178°W includes most of the central northern Pacific north of 45° and east of 180°. It is characteristically colder and less saline than the Transitional Domain, with near-surface salinity generally between 32.4 and 32.8 ppt. The measured values ranged between 32.7 and 32.9 ppt near the surface and rose to 33.3 ppt at the bottom of the mixed layer (approximately 100 meters). There was a very pronounced halocline between 100 and 200 meters. Salinity reached 34.0 ppt at 400 meters.

2. NORTHWEST PACIFIC   Stations D, E, F, G: data collected from 28 Feb to 11 Mar.

This portion of the cruise traversed from 50°48'N, 180° to 45°30'N, 153°30'E and includes part of the Western Subarctic Domain.[15] This domain is characteristically colder and somewhat more saline than the remainder of the northern Pacific Ocean. The extent of the domain is defined by temperatures below 3.5°C at the bottom of the mixed layer. On stations E, F, and G the mixed layer temperatures approached 0°C and there was a sharp thermocline between 90 and 120 meters in which temperatures rose to about 3.5°C. Salinities on these stations varied between 33.0 and 33.2 ppt in the surface layer, and a fairly well-developed halocline was observed between 75 and 150 meters; the salinity reached 34.0 ppt between 200 and 500 meters. Near surface temperature on station D was warmer than the other stations occupied in this region and its observed thermocline was less well-defined and salinity was somewhat higher than exhibited on stations E, F, and G, as shown in Figure 2.

O, T and V. Typically, two hauls were made per station as near midday or midnight as possible. During each haul, net depth was determined by a Benthos model 1040 Depth Telemetering Pinger and was read aboard ship from a Westrex Mark 10-A Precision Depth Recorder. Because of the varying water depths and types of hauls sampled, maximum haul depths ranged between 69 and 335 meters. All hauls were made with the ship towing at a speed of about 1.5 knots, or 46 meters per minute.

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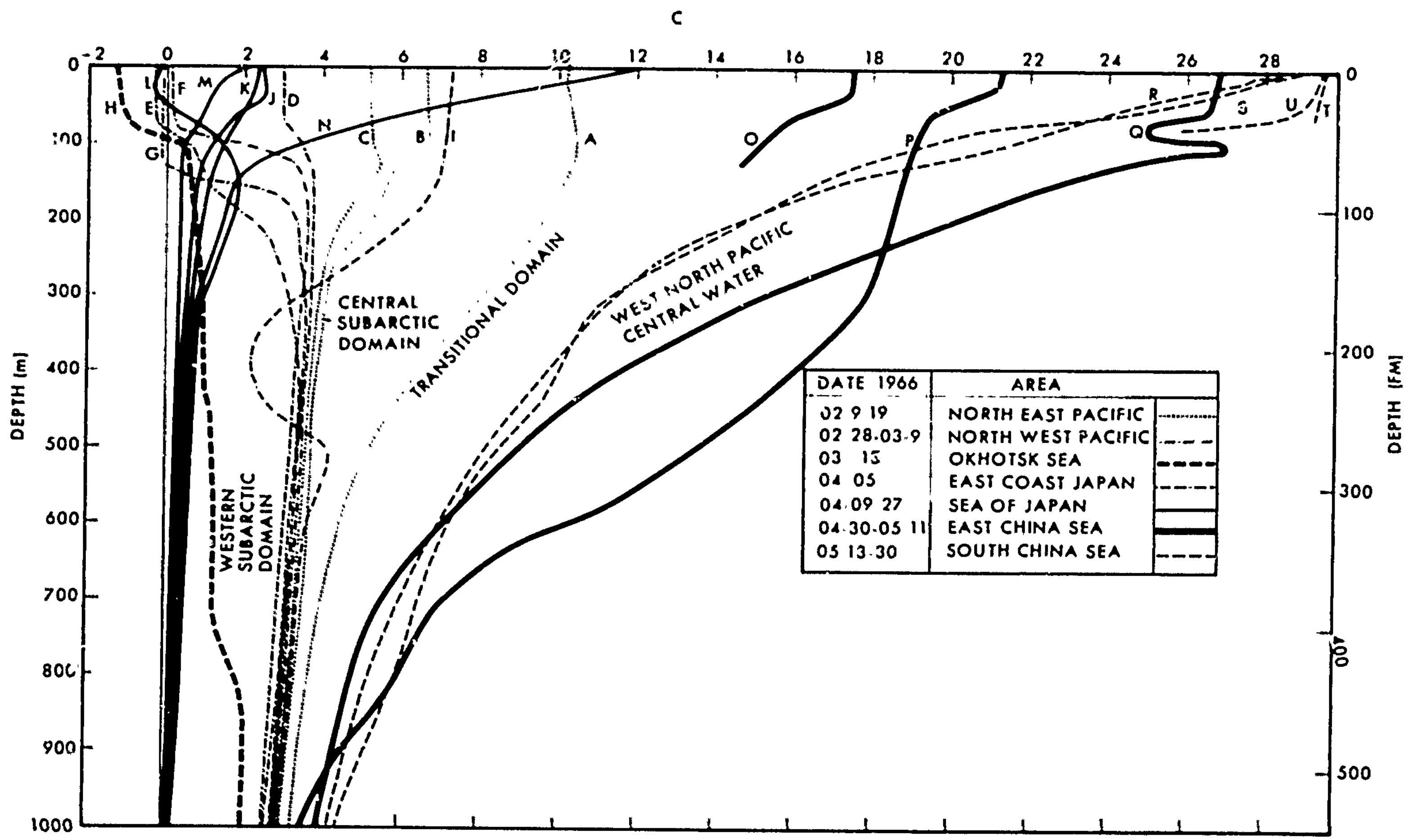


Figure 2 Station temperature profiles

3. SEA OF OKHOTSK   Station H; data collected from 12 Mar to 15 Mar.

The Okhotsk Sea is considered to be within the Western Subarctic Domain[15], and was traversed from 45°30'N, 152°30'E to 45°47'N, 150°46'E. However, because of the enclosed nature of the basin and its associated lower temperature and salinity, it is considered separately here. Near-surface temperatures were below −1.0°C and the mixed layer extended to about 50 meters. Salinity was low, 32.7 ppt near the surface. The thermocline extended to 100 meters and there was a gradual increase in temperature with depth to a maximum of 2.1°C at 1500 meters. Similarly, a halocline existed between 50 and 150 meters, below which salinity gradually increased to 34.0 ppt at 850 meters.

4. WESTERN PACIFIC   No station data collected; 16 Mar to 2 Apr.

No stations were occupied in the western Pacific region which was traversed from 45°47'N, 150°46'E to 35°47'N, 141°13'E. Consequently, the physical parameters of the water were not measured. The area traversed has previously been identified to include the western edge of the Western Subarctic Domain[15] and the northern edge of the Western North Pacific Central Waters.[15] Thus, this region may be considered as physically transitional with characteristics of both the Subarctic and the Central watermasses; water would be expected to warm and increase in salinity in the southerly direction.

5. EAST COAST OF JAPAN   Station I; data collected from 3 April to 8 April.

The water near the east coast of Japan, occupied from 35°47'N, 141°13'E to 41°39'N, 141°28'E, has complex physical characteristics. It combines characteristics of both the Western Subarctic Domain and Western North Pacific Central Water. Additionally, it is affected by water from the Sea of Japan flowing into the Pacific basin through the Tsugaru Strait, and is in the transitional area between the cold southerly flow of the Oyashio Current and the warm northerly flow of the Kuroshio Current. Temperature was measured several times on station I and the results were varied. Some of the measurements showed mixing to at least 200 meters and a nearly constant temperature of 6 to 7°C with depth (see figure 2); other measurements showed a shallow, cold mixed layer, near 1°C, to about 20 meters and a sharp thermocline, with the temperature increasing to 6°C at 35 meters. The area surveyed also showed a strong cold water intrusion, probably from the Sea of Japan, at about 400 meters within which the temperature decrreased to 2.5°C (see figure 2). The observed salinity was generally intermediate between that typically shown in the Western Subarctic region and the Sea of Japan, with observed near-surface values of 33.8 ppt increasing to 34.0 ppt at 600 meters. The salinity also reflected an intermediate-depth intrusion of water; values decreased to 33.5 ppt at 300 meters before reversing and starting to rise at greater depths. Apparently, physical conditions in the vicinity of station I are determined by local conditions, the intersection of several watermass types, and the influence of the Kuroshio current system which flows northward through this region.

6. SEA OF JAPAN - Stations J, K, L, M, N, data collected from 8 April to 29 April.

Near-surface temperature and salinity vary considerably in the Japan Sea (41°31'N, 141°28'E to 33°30'N, 129°21'E). The northern portion, at station L (47°29'N, 143°43'E), was near 0°C with a salinity of 33.5 ppt, the southernmost station, N, near the Tsushima

Strait, showed a temperature of over 12° C and a salinity of 34.4 ppt near the surface. Intermediate water in the Sea of Japan ranged in temperature between 0.12° and 0.14° C to 1000 meters and had salinities near 34.0 ppt throughout the same interval.

Stations L and N indicated very little surface mixing, with thermoclines and haloclines to approximately 100 meters. Station N had the unusual characteristic of decreasing salinity to 2000 meters. Stations J, K, and M appeared to be well-mixed throughout the water column.

7. EAST CHINA SEA — Stations O, P, Q, data collected from 30 April to 12 May.

Stations O, P, and Q are geographically located from 33°30'N, 129°21'E to 20°46'N, 120°15'E. Stations P and Q were deep-water stations within the Western North Pacific Central Watermass,[16] which is characterized by relatively high temperatures and salinities. The surface temperatures varied on these stations from 17.6° C to 26.8° C and salinities varied from 34.6 to 34.7 ppt. There was a shallow mixed layer (to 20 meters) below which temperatures decreased to a minimum of 3.9° C at 1000 meters. At all stations in this region, minimum salinities were above 34.0 ppt.

Station O was in a shallow coastal region of less than 140 meters. The mixed layer, with a temperature of 17.6° C, extended to 30 meters; the temperature at the bottom was 15.1° C. Salinity varied from 34.2 to 34.4 ppt.

8. SOUTH CHINA SEA — Stations R, S, T, U, data collected from 13 May to 3 June.

The area traversed during the last segment of the cruise was from 20°46'N, 120°15'E to Subic Bay, P.I. This geographical position and the enclosed nature of the South China Sea produce high surface temperatures and relatively low salinities due to the dilution effects of precipitation and river run-off. Stations R and S had near-surface temperatures above 28° C and salinities between 33.6 and 33.9 ppt. Surface mixing was not evident.

Stations T and U were in very shallow water (depths less than 100 meters) and had surface temperatures above 29° C and low surface salinities (near 32.8 ppt) which increased to between 33.5 and 33.8 ppt near the bottom. For station salinity profiles, see Figures 3(a) and (b).

It must be emphasized that the regions discussed above were distinguished primarily on the basis of their physical characteristics observed during EASOR II operations although historic generalizations of regional properties previously found[15, 16] were also considered. The observations on each station were treated as time-independent, although actual conditions, particularly within 200 meters or so of the surface, doubtless exhibit temporal variations. However, general agreement in the delineation of regions on the basis of our data and those delineated historically indicates that, although the values of the physical characteristics might vary temporally within the various regions, the regions themselves remain distinctive, one from another, through time.

The regions, then, provide convenient divisions, based on physical characteristics, within which other properties and observations may be related.

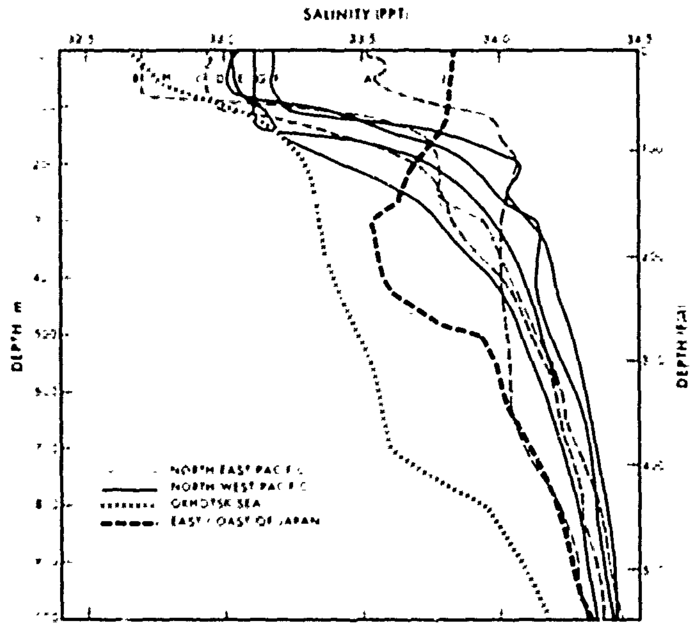


Figure 3(a) Station salinity profiles Stations A – I

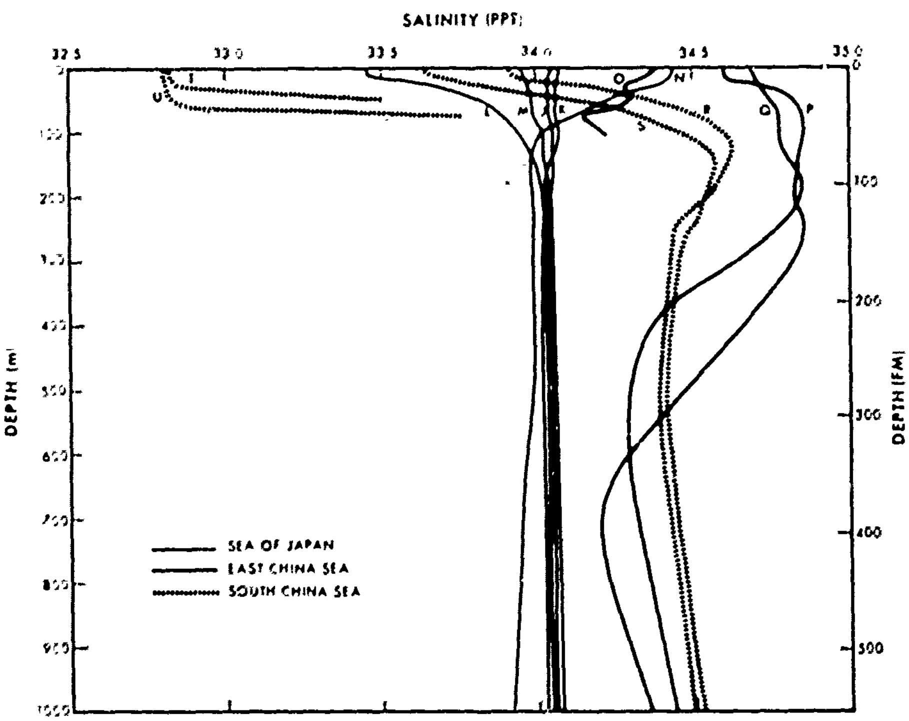


Figure 3(b) Station salinity profiles. Stations J – U

DATA ANALYSIS AND RESULTS

ACOUSTIC SCATTERING

Large Echo Groups (LEGs)

The EASOR II cruise track and the general distribution of LEGs and their day and night densities are shown in figure 1. LEGs appear to be concentrated mainly in the near-shore regions and marginal seas, particularly in the Sea of Japan and adjacent areas. Few LEGs were observed in the Northeast Pacific; a small number were counted between San Diego and Station A and on Station C. A more complete record of the mean LEG densities (number of LEGs per million cubic meters)* and the ranges of values in a 12-hour day or night period are given in figure 4. For computational purposes, each nychthemeral interval began at 0600 and was given the date of the calendar day at that time. For each day (0600-1759) or night (1800-0559) period within each interval, the LEG density (number per million cubic meters) in each hourly segment was tallied. The mean value and range of the non-zero observations are presented in figure 4, along with the number of hourly segments in which LEGs were observed within the given 12-hour period. Both the Sea of Japan and the Okhotsk Sea had high densities of LEGs, with lesser numbers in the Northwest Pacific, the East China Sea and off the East Coast of Japan. As shown in figure 4, the range of values in any given 12-hour period can be very large and there is as much as three orders of magnitude difference between means for different areas.

The percentage of time that LEGs were observed within each regional area for day and night observations is shown in Figure 5. Values were obtained by dividing the day or night hourly occurrence of LEGs by the total number of hours that the recorder was in operation during any one period. The highest frequencies of occurrence were recorded in the Sea of Japan, the East Coast of Japan, and the Sea of Okhotsk. The percent frequency recorded in the Northeast Pacific was less than 15. On the average for all areas surveyed, the day frequency of occurrence exceeded the night frequency.

Area means for both LEG density and frequency of occurrence are listed in Table 2. Although the variability within the indicated physical areas is quite high, mean values show general station differences.

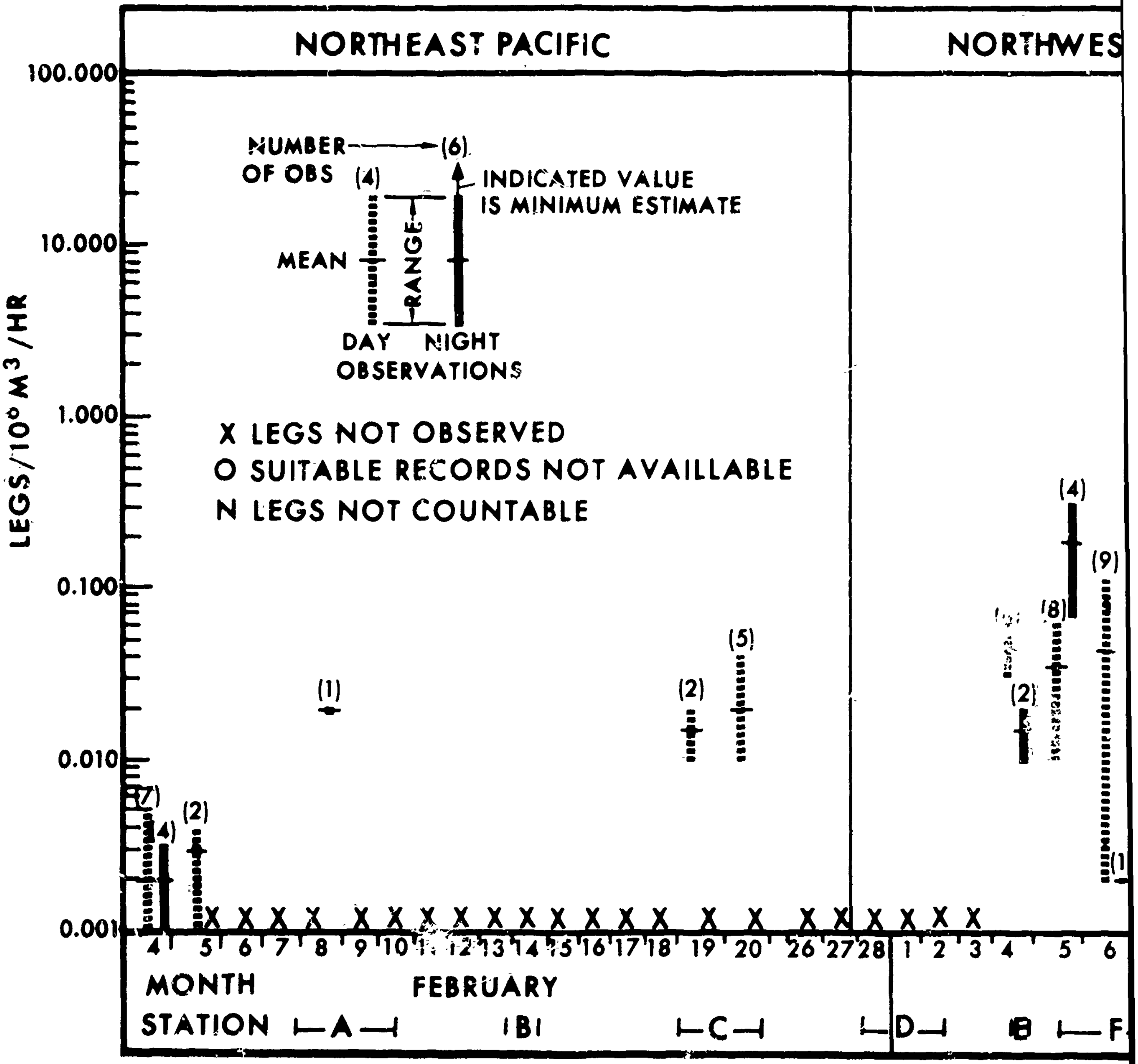
Figure 6 displays the density of LEGs on individual stations. Although the trend of LEG densities while on station is similar to the overall area densities, the numbers recorded are generally higher. Potential reasons for this anomaly are discussed later. The densities vary from 0 to greater than 1 LEG/$10^6 m^3$ of water. The highest value encountered, 1.4 LEG/$10^6 m^3$, was in the Sea of Okhotsk during the day.

*Note: A ship traveling at a cruising speed of 10 knots, utilizing directional transducers as described, will acoustically search 1.0 × $10^6 m^3$ in approximately 4 seconds.

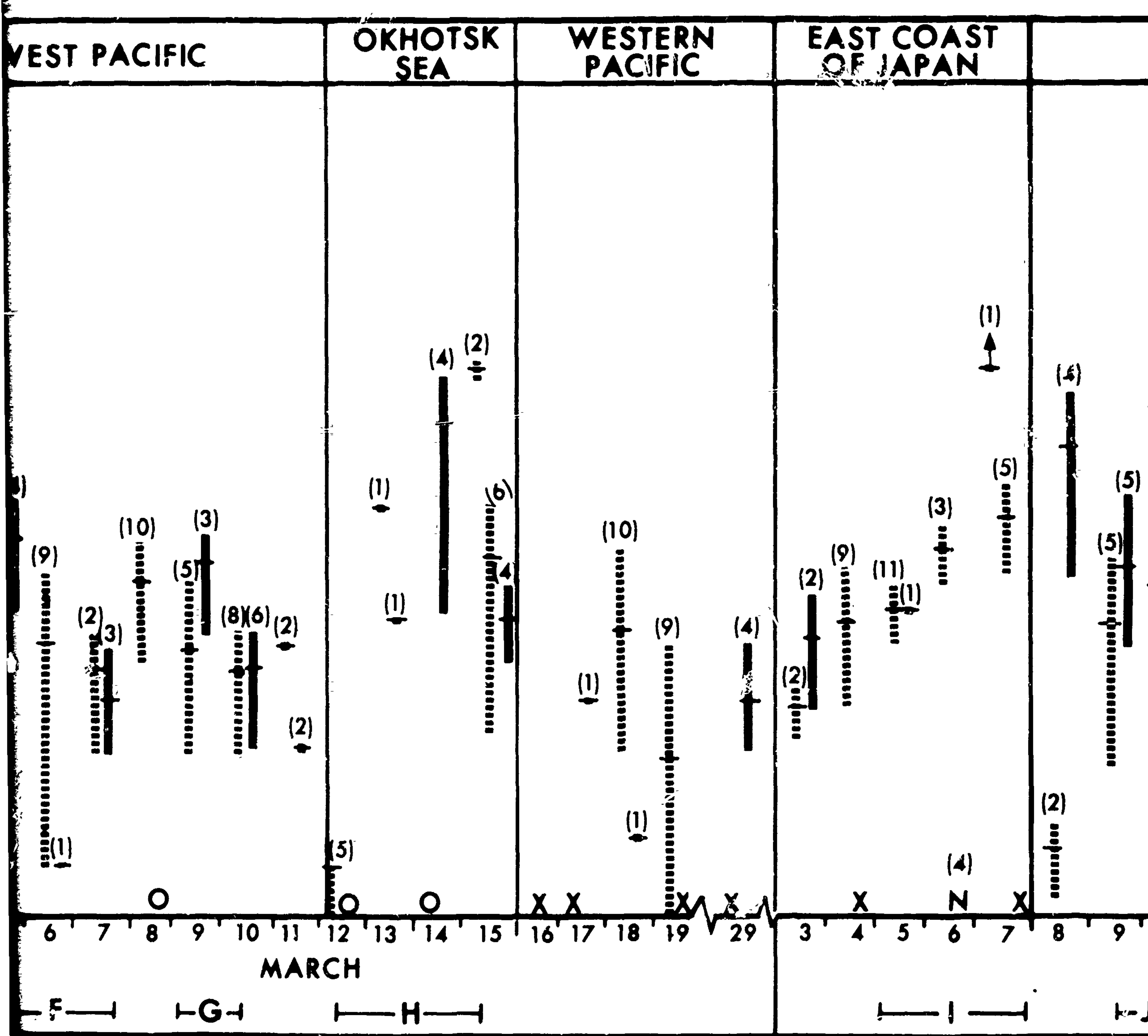
Table 2. Mean LEG Densities and Frequencies of Occurrence

Geographical Area	Mean LEG density (No. $10^6 m^3$)		Mean LEG frequency (% occurrence*)	
	Day	Night	Day	Night
N. E. Pacific	0.001	0.0001	12	4
N. W. Pacific	0.021	0.014	41	22
Okhotsk Sea	0.214	0.121	58	27
Western Pacific	0.014	0.002	40	14
East Coast Japan	0.086	0.004	67	28
Sea of Japan	0.120	0.211	77	56
East China Sea	0.009	0.006	16	15
South China Sea	0.022	0.003	48	16

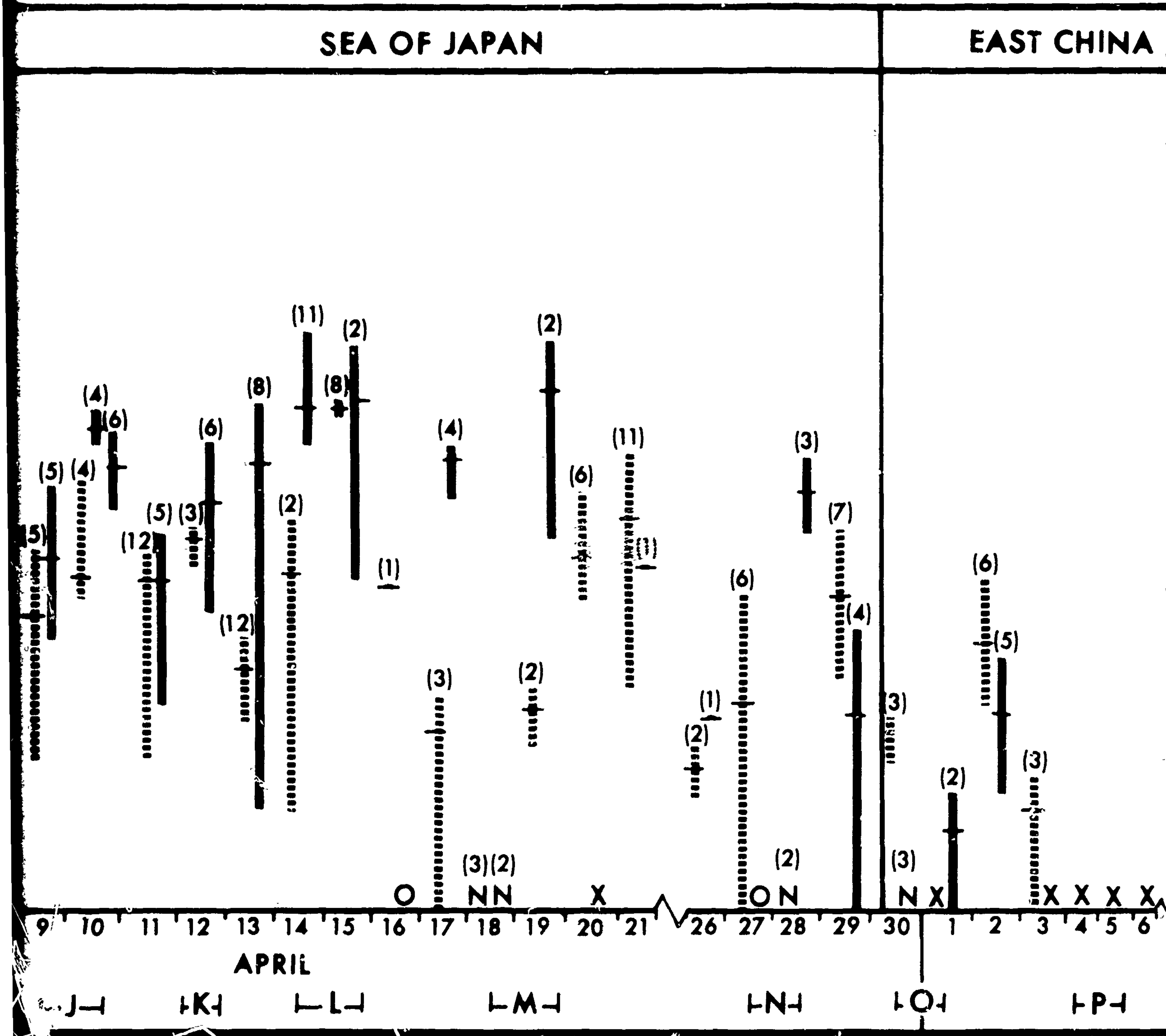
$$\text{*\% occurrence} = \left(\frac{\text{hours in which LEGs were observed}}{\text{Total hours of recorder operation}}\right) \times 100$$



NORTHEAST PACIFIC
NORTHWES
100.000
10.000
1.000
0.100
0.010
0.001
LEGS/10⁶ M³/HR
NUMBER OF OBS
(6)
(4)
INDICATED VALUE IS MINIMUM ESTIMATE
MEAN
RANGE
DAY NIGHT
OBSERVATIONS
X LEGS NOT OBSERVED
O SUITABLE RECORDS NOT AVAILABLE
N LEGS NOT COUNTABLE
MONTH
FEBRUARY
STATION
A
B
C
D
F



VEST PACIFIC
OKHOTSK SEA
WESTERN PACIFIC
EAST COAST OF JAPAN
6 7 8 9 10 11 12 13 14 15 16 17 18 19 29 3 4 5 6 7 8 9
MARCH
F
G
H
I
J



SEA OF JAPAN
EAST CHINA
(5) (5) (4) (4) (6) (12) (5) (3) (6) (12) (8) (2) (11) (8) (2) (1) (4) (3) (2) (2) (6) (11) (1) (2) (1) (6) (3) (7) (4) (3) (3) (2) (6) (5) (3)
O NN X ON N X X X X X X
(3)(2) (2) (3)
9 10 11 12 13 14 15 16 17 18 19 20 21 26 27 28 29 30 1 2 3 4 5 6
APRIL
J K L M N O P

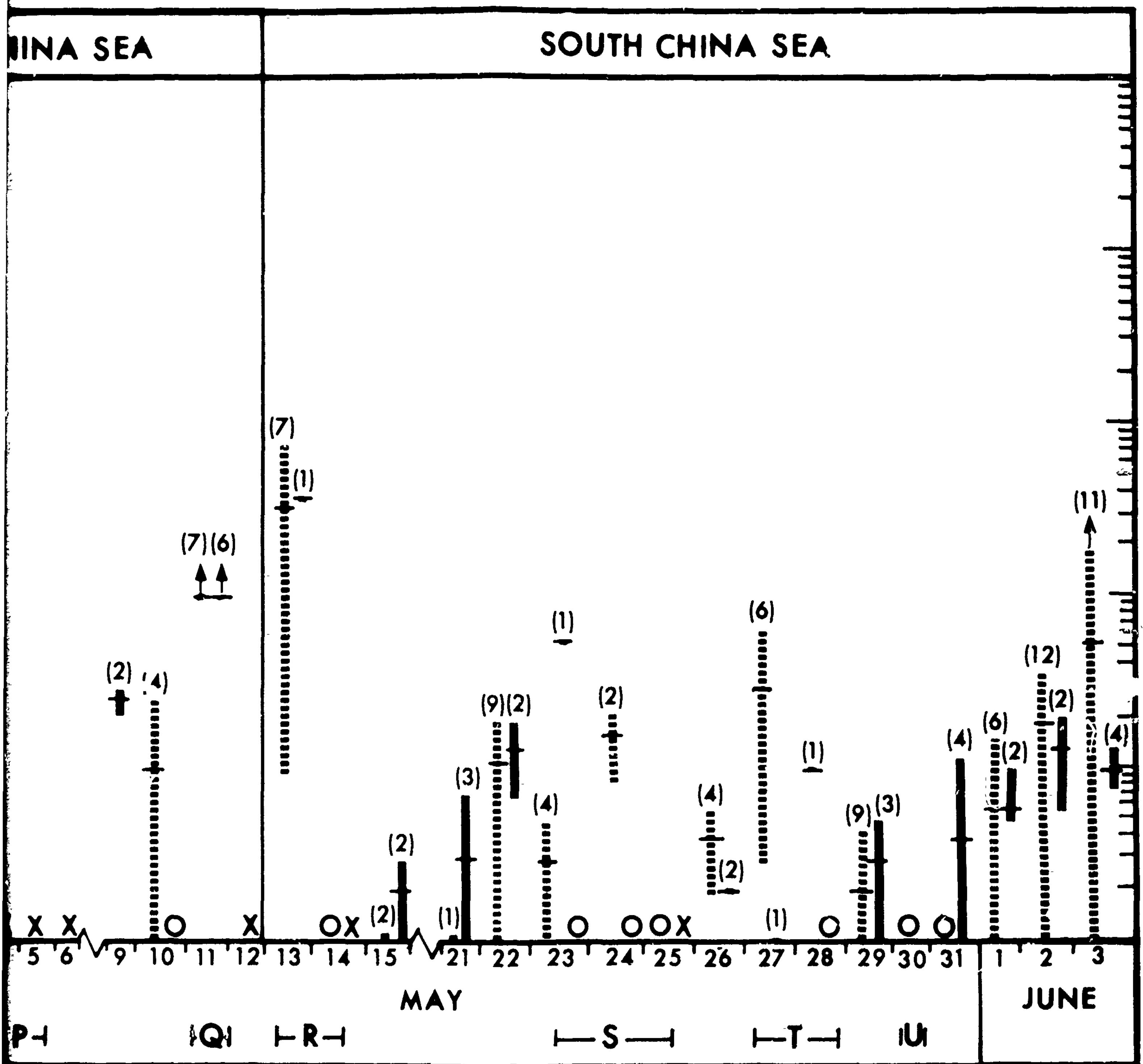


Figure 4 LEG density distribution shown for 12 hour day and night segments over the duration of the cruise.

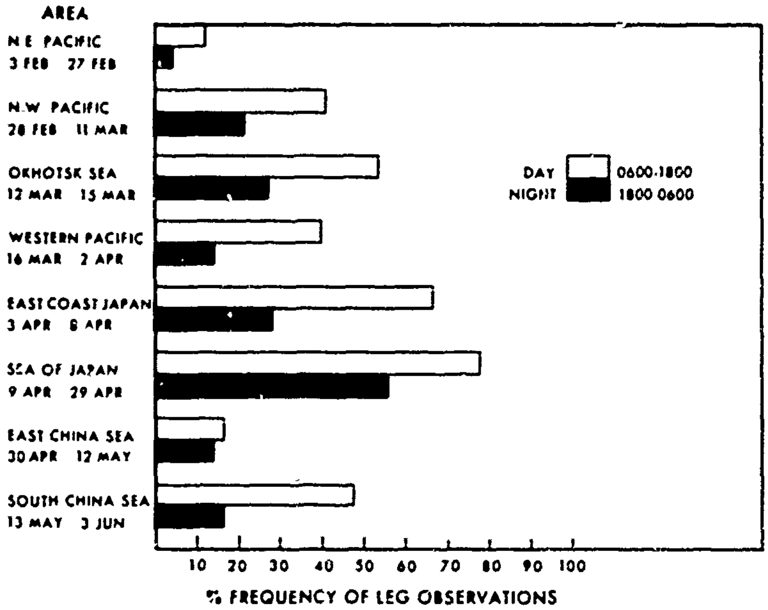


Figure 5. Percent of frequency that LEGs were observed (number of hourly LEG observations/total number of hours recorded by regional area.

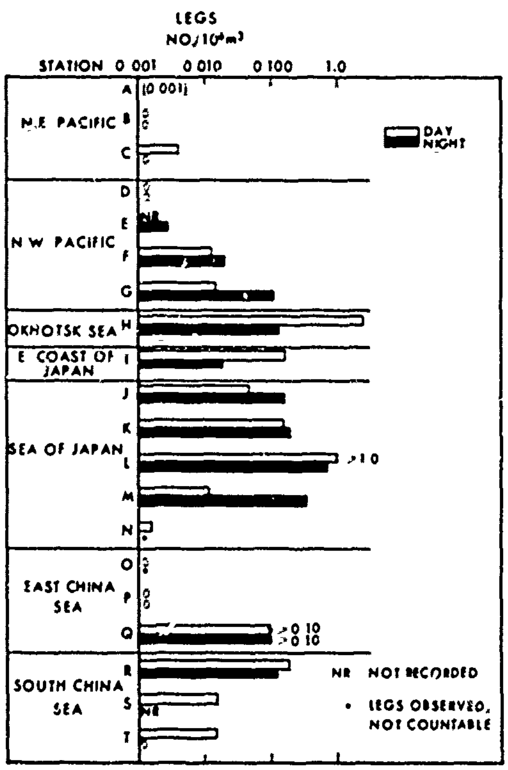


Figure 6. Station LEG densities (number of LEGs/10^6 m^3).

Deep Scattering Layers

Scattering layers, recorded at 12 kHz throughout the cruise, are represented in figure 7. Photographs of representative sections of echo sounder records for day and night scattering are presented in Appendix A. Figure 7 is separated into geographic areas and subdivided further into areas of physical similarities (domains) in an attempt to facilitate eventual correlation of scattering conditions with watermass characteristics.

Scattering layers were nearly ubiquitous, with the exception of the Sea of Japan at which site layers were recorded only near the Korea Strait. Table 3 shows the frequency of occurrence of 12 kHz scattering layers. Because the scattering layers as represented on the echo sounder records are a function of variable signal length, gain setting and noise interference, both the percent frequencies shown in Table 3 and the layers represented in figure 7 should be considered as general approximations.

Table 3. Frequency of Occurrence of Scattering Layers by Areas

Regional Area	Frequency of observations (% of total day or night periods) Day	Night
N. E. Pacific	88.9	87.5
Transitional Domain	100	100
Central Subarctic Domain	80	75
N. W. Pacific	100	100
Okhotsk Sea	100*	100*
Western Pacific	100*	100*
East Coast Japan	100	100
Sea of Japan	21	15.4
East China Sea	77.8	87.5
South China Sea	90.9	90.9

*less than 5 observations

The regional patterns of scattering varied considerably in the depth, number and thickness of layers and in their relative scattering intensity, as shown on the echo sounder record of figure 7. Following is a general description of these scattering patterns by geographical area.

1. NORTHEAST PACIFIC

- Transitional Domain

Multiple layers and a relatively complex pattern of scattering characterized this area. Layers were mostly between 75 and 250 fathoms by day and between 150 fathoms and the sea surface at night; layers underwent extensive vertical migrations during crepuscular periods.

- Central Subarctic Domain

A single layer at mid-depths, 150 to 225 fathoms, was typically observed. The layer did not migrate extensively and near-surface layers were rare.

2. NORTHWEST PACIFIC (Western Subarctic Domain)

The pattern of scattering was again complex. Multiple layers were generally observed between 75 and 225 fathoms diurnally and from 50 to 150 fathoms at night. Night scattering was less complex than day. The scattering layers tended to remain below the depth of the thermocline between station D and F.

3. SEA OF OKHOTSK

Although the record is sparse, the observed scattering in this area was characterized by a single, rather deep layer from approximately 170 to 200 fathoms and diffusive scattering to 350 fathoms. The only night scattering observed was a thin layer at 40 fathoms.

4. WESTERN PACIFIC

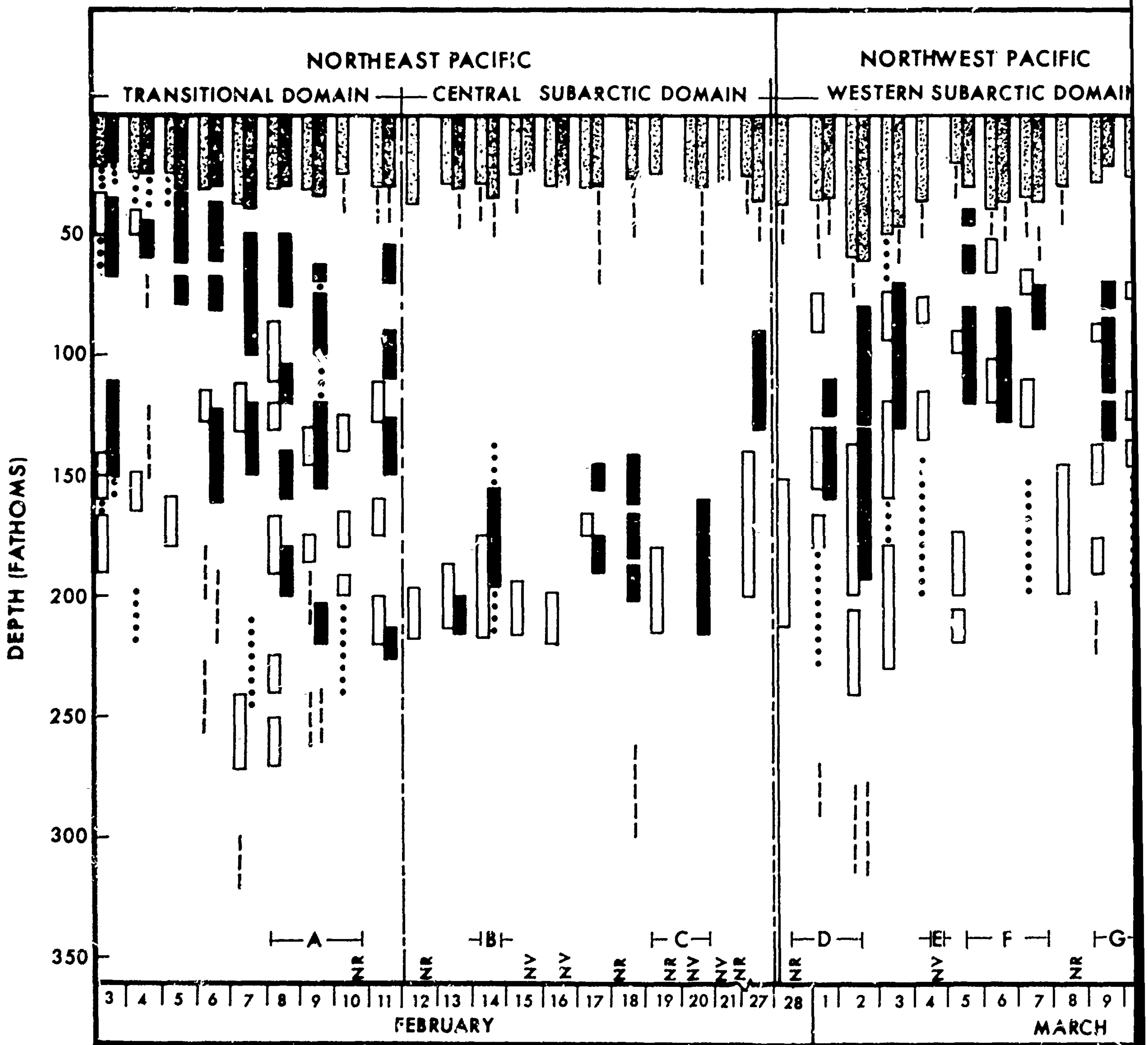
Initially, the scattering was similar to that observed in the Central Subarctic Domain, *e.g.*, a single, apparently non-migratory layer between 140 and 200 fathoms. More extensive diffusive scattering and near-surface layers were evident as the eastern coast of Japan was approached.

5. EAST COAST OF JAPAN

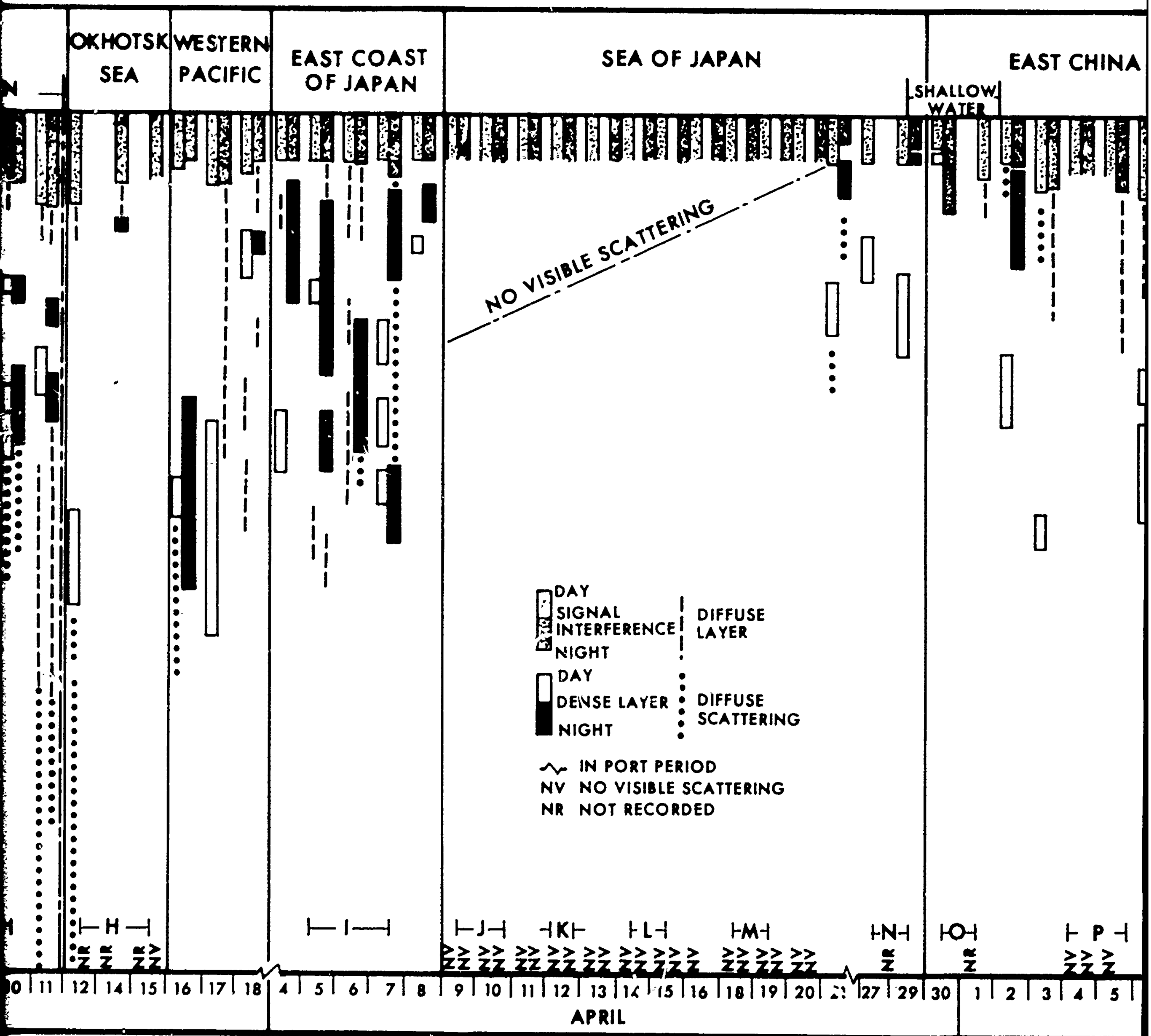
During the day, layers were generally observed between 120 and 150 fathoms in this area. A layer of distinctive targets (individuals or groups) was frequently observed between 50 and 70 fathoms. Both the layer of targets and the deepter, more diffusive scattering layers migrated into the near-surface zone at approximately 1800; a non-migratory layer remained near 150 fathoms.

6. SEA OF JAPAN

Scattering, particularly in the form of horizontally-stratified, diffusive scattering layers, was virtually absent in the interior portion of the Japan Sea. Scattering layers were recorded at depths generally above 100 fathoms between the Korea Strait and station N.



NORTHEAST PACIFIC
TRANSITIONAL DOMAIN
CENTRAL SUBARCTIC DOMAIN
NORTHWEST PACIFIC
WESTERN SUBARCTIC DOMAI
DEPTH (FATHOMS)
50
100
150
200
250
300
350
A
B
C
D
E
F
G
NR
NV
3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 27 28 1 2 3 4 5 6 7 8 9
FEBRUARY
MARCH



OKHOTSK SEA
WESTERN PACIFIC
EAST COAST OF JAPAN
SEA OF JAPAN
EAST CHINA
SHALLOW WATER
NO VISIBLE SCATTERING
DAY
SIGNAL INTERFERENCE
NIGHT
DIFFUSE LAYER
DAY
DENSE LAYER
NIGHT
DIFFUSE SCATTERING
IN PORT PERIOD
NV NO VISIBLE SCATTERING
NR NOT RECORDED
H
I
J
K
L
M
N
O
P
NR
NV
10 11 12 14 15 16 17 18 4 5 6 7 8 9 10 11 12 13 14 15 16 18 19 20 27 29 30 1 2 3 4 5
APRIL

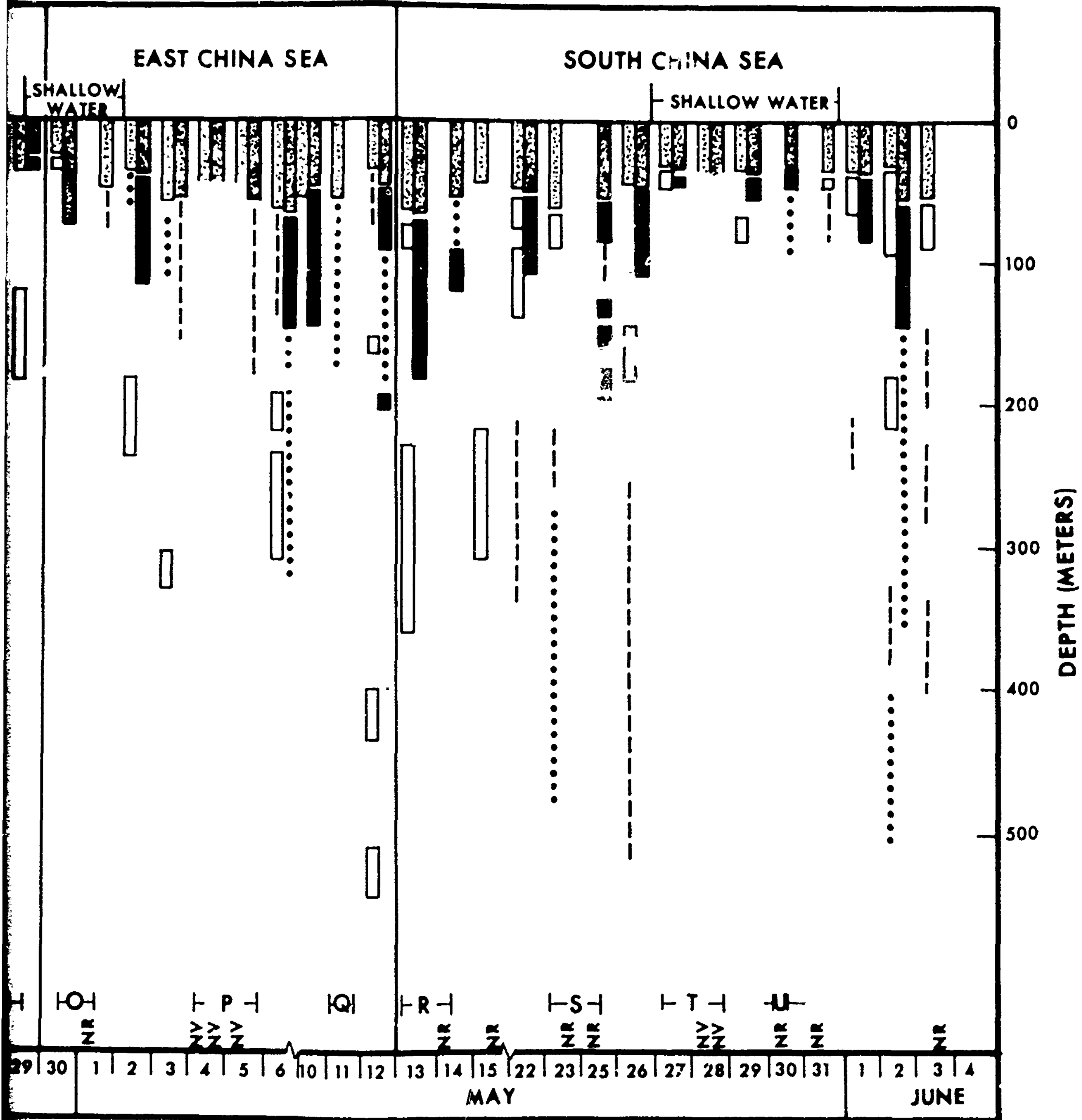


Figure 7. Scattering layer profiles (depth and relative intensity of layers are given for approximately noon and midnight) Scattering layers are taken from 12 kHz PDR records.

7. EAST CHINA SEA

Dense layering was typically observed in this area in the interval from 100 to 175 fathoms by day and 20 to 75 fathoms at night. Station O was in shallow water and only near-surface scattering was observed.

8. SOUTH CHINA SEA

During the day, a deep, thick, diffusive layer, which extended to approximately 275 fathoms, and a thin, near-surface layer, which remained above 75 fathoms, were generally observed in this area. Nocturnal scattering was characterized by near-surface layers at approximately 75 fathoms and diffusive scattering below that depth. The shallow-water stations, T and U, exhibited scattering near the bottom between 50 and 100 meters.

BIOLOGICAL OBSERVATIONS

The biological data collected during FASOR II operations are summarized in Tables 4 and 5. The division of plankton into Primary and Secondary categories in Table 4 is based on the probable contribution of each type of plankton to volume scattering, the size, structure and abundance of each type of plankton were all considered in the classification. As a result, for the acoustic frequencies of greatest interest here, the importance of the different categories of organisms to volume scattering increases from top to bottom in Table 4, *i.e.*, fishes are considered as more important than secondary plankton to volume scattering.[17,18] There are two categories of fishes in Table 4. Mesopelagic Fishes, which includes typical migratory components of the Deep Scattering Layer (Myctophids, Gonostomatids, Bathylagids, etc.) and Other Fishes, which are principally juvenile and larval forms of fishes from, typically, the mixed layer of the sea. The displacement volume of the fishes taken in some of the hauls is also listed in Table 4. The fish displacement volumes are part of the total displacement volumes (Total Catch) and the difference between the two volumes for a particular haul is the displacement volume of the plankton in the haul. Table 5 gives a further account of the fishes collected during FASOR II operations, listing species and the region from which they were taken. Appendix B gives the total number and size range of fish collected on each station. Histograms of plankton volume and fish concentration from each station are given in, respectively, Figures 8 and 9. The major biological trends by geographical area, with respect to collected primary plankton, secondary plankton and fish, are discussed on the following pages.

Table 4. Concentrations of organisms, in number of individuals per 1000 m^3 of water sampled. Concentrations less than 1 individual per 1000 m^3 are indicated by Tr (Trace).

	Station											
	A		B		C		D		E	F	H	
Haul Number	1	2	3	4	5	6	7	8	9	10	11	12
Time of Day	Night	Day	Night	Day	Night	Day	Day	Night	Night	Day	Day	Night
Volume Filtered (m^3)	6950	2633	5668	5676	4886	6175	4784	5921	3431	6519	5652	8016
Maximum Sampling Depth (m)	265	255	210	245	200	185	280	335	195	155	230	225
Displacement Volumes (ml/$10^3 m^3$)												
Total Catch	47	23	55	46	37	19	27†	24	26	12	2	50
Fishes Only			8.8		20.5							
"Secondary" Plankton												
Medusae			1	127	61	134	55	98	55	78	1	
Chaetognaths	3	8	93	114	4	1	132	104	28	107	11	40
Copepods								61	6	33		
Amphipods	Tr	1	Tr		4	3			5		2	27
"Primary" Plankton												
Mysids					1							
Euphausiids	14	6	98	14	58	2	162	20	173	8	10	513
Decapods	2		36	497	8							
Fishes												
Mesopelagic	3.3		3.5		16.6			0.7	0.3			0.1
Others*			0.7					0.2				

*Category includes larvae and juveniles as well as adult, non-mesopelagic forms.

†About 600 ml (125 ml/$10^3 m^3$) of gelatinous organisms removed before the displacement measurement.

Table 4. (Continued).

	Station										
	I			J		K		I		M	
Haul Number	13	14	15	16	17	18	19	20	21	22	23
Time of Day	Day	Day	Night	Day	Night	Day	Night	Day	Night	Day	Night
Volume Filtered (m^3)	3875	5883	5504	5437	5054	8649	8973	5435	13980	5092	4749
Maximum Sampling Depth (m)	275	305	280	195	175	295	230	175	200	225	240
Displacement Volumes (ml $10^3 m^3$)											
Total Catch	28	16	113	5	99	9	65	14	20	16	45
Fishes Only			45.4								
"Secondary" Plankton											
Medusae	7	6	7							17	
Chaetognaths	66	25	64		328	35	55	112	55	28	16
Copepods	51	63	100	1	350	13	141	32	24	134	212
Amphipods	6	55		8	57	1	16	8	20	4	48
"Primary" Plankton											
Mysids					13		1		7		18
Euphausiids	14	8	274	75	366	67	666	108	126	3	435
Decapods			1		1						
Fishes											
Mesopelagic		0.8	16.5								
Others*	0.3	0.2	0.2		0.8	0.1	0.1		0.1		

*Category includes larvae and juveniles as well as adult, non-mesopelagic forms.

Hauls made at ship speed of 3 kt (93 m min^{-1}).

Table 4. (Continued).

	Station N		O	P		Q	R		S	
Haul Number	24	25	26	27	28	29	30	31	32	33
Time of Day	Day	Night	Day	Day	Night	Night	Day	Night	Day	Night
Volume Filtered (m^3)	3619	4953	3003	6429	5978	6128	6367	5839	5472	4024
Maximum Sampling Depth (m)	210	207	75	261	165	261	198	174	192	210
Displacement Volumes ($ml/10^3m^3$)										
Total Catch	25	50	**	6	17	6	11	24	6	20
Fishes Only					2.5	1.6	0.8	8.6=		9.9
"Secondary" Plankton										
Medusae							Tr			
Chaetognaths	15	49		27		2	6	5		2
Copepods	38	81								
Amphipods	87	230		1	Tr	Tr	Tr	2		Tr
"Trimary" Plankton										
Mysids		3				1		1		
Euphausiids	6	109		1	48	7		14		8
Decapods		1		1	10	4	1	3	Tr	6
Fishes										
Mesopelagic					4.2					2.7
Others*	–	0.2	–	1.2	0.3	9.0	2.2	6.7=	2.2	4.2

*Category includes larvae and juveniles as well as adult, non-mesopelagic forms.

**Haul clogged with salps. Displacement volume estimated to be 10^4 ml (3330 $ml/10^3m^3$). Sorting of sample impossible.

=Data from original sorting record only; no further identification available.

Table 4. (Continued).

	Station				
	T			U	
Haul Number	34	35	36	37	38
Time of Day	Day	Day	Night	Day	Night
Volume Filtered (m^3)	5032	4475	5223	3556	2817
Maximum Sampling Depth (m)	93[a]	84[a]	93[a]	69[a]	69
Displacement Volumes (ml $10^3 m^3$)					
Total Catch		6	10#	18	
Fishes Only					
"Secondary" Plankton					
Medusae			Tr		1
Chaetognaths					11
Copepods					
Amphipods					4
"Primary" Plankton					
Mysids					3
Euphausiids					
Decapods	Tr		Tr		2
Fishes					
Mesopelagic					
Others*		4.5#	9.6	1.4	23.1

*Category includes larvae and juveniles as well as adult, non-mesopelagic forms.

[a]Hauls encountered seabed for unknown length of time. Sorting and volumetric measurements difficult or impossible.

#Values estimated from observations made at the time of the haul.

Table 5. FASOR II Fish Occurrence for Day and Night by Region

Region	TD	CD	NP	SO	ECJ		SJ		ECS		SCS			
Type of Haul(s)	N	N	N	N	D	N	D	N	D	N	D	N	S	Total
MESOPELAGIC FISHES														
Family MYCTOPHIDAE Lanternfishes														
Ceratoscopelus warmingi					-	-	-		-	X		X	-	2
Diaphus effulgens	-						-	-	-	X	-	-	-	1
D. garmani		-			-	-	-	-	-	-		X	-	1
D. mollis			-	-		-		-		-	-	X	-	1
D. theta		X			X	X	-	-		-				4
D. sp.	X						-		-	-			-	1
Lampanyctus guentheri	X			-	-	-	-	-	-		-	-	-	1
L. jordani	X			-	X				-	-	-		-	2
L. punctatissimus						-	-	-		-		X	-	1
L. ritteri	X					-	-	-			-		-	1
L. tenuiformis									-	X	-	X	-	2
Notoscopelus hoffmanni							-			X		X	-	2
Stenobrachius leucopsarus		X	X			X					-			5
Tarletonbeania crenularis		X				-	-	-			-			2
Family GONOSTOMATIDAE Lightfishes														
Gonostoma gracile				-	X	X	-	-		X	-			3
Vinciguerria nimbaria				-		-	-	-	-	X				1
V. sp.				-			-		-	-		X		1
Family BATHYLAGIDAE Blacksmelts														
Bathylagus ochotensis		X			-	X	-				-		-	2
Leuroglossus stilbius			X	X		-	-	-	-				-	2
Bathylagid Larva			X		-	-	-	-			-			1
Family IDIACANTHIDAE Blackdragons														
Idiacanthus antrostomus	X	-				-	-	-			-	-		1
Family STERNOPTYCHIDAE Hatchetfishes														
Argyropelecus lychnus	X					-	-	-	-	-		-		1
Family MELANOSTOMIATIDAE Scaleless Dragonfishes														
Opostomias sp.	X			-	-			-		-				1
Tactostoma macropus	X				-	-	-		-	-				1
Family SCOPELARCHIDAE Pearleyes														
Neoscopelarchoides dentatus			-			X	-	-	-		-			1
Scopelarchid Larva				-		X	-			-				1
Family STOMIATIDAE Scaly Dragonfishes														
Stomias affinis							-	-	-			X		1
S. sp.	-						-		-	X			-	1
OTHER FISHES														
Family EXOCOETIDAE Flying Fishes														
Exocoetus vinciguerre							-	-			-	X		1
Family Indefinite														
Juvenile Fishes					X		X	X	-	X		X	X	8
Leptocephalus Larva							-			X		X	-	2
Miscellaneous Larvae		X		-	X	-		X	X	X	X	-	X	10
Unidentified Fishes					-		-			-	X	-	X	2
Regional Haul-Type Total	8	5	3	1	5	6	1	2	1	10	2	11	3	

TD: Transitional Domain CD: Central Subarctic Domain NP: Northwest Pacific SO: Sea of Okhotsk ECJ: East Coast of Japan SJ: Sea of Japan ECS: East China Sea SCS: South China Sea

N: Night D: Day S: Shallow-Water Total: Total number of *HAULS* in which the type of fish was taken.

X: Occurrence – Non-occurrence

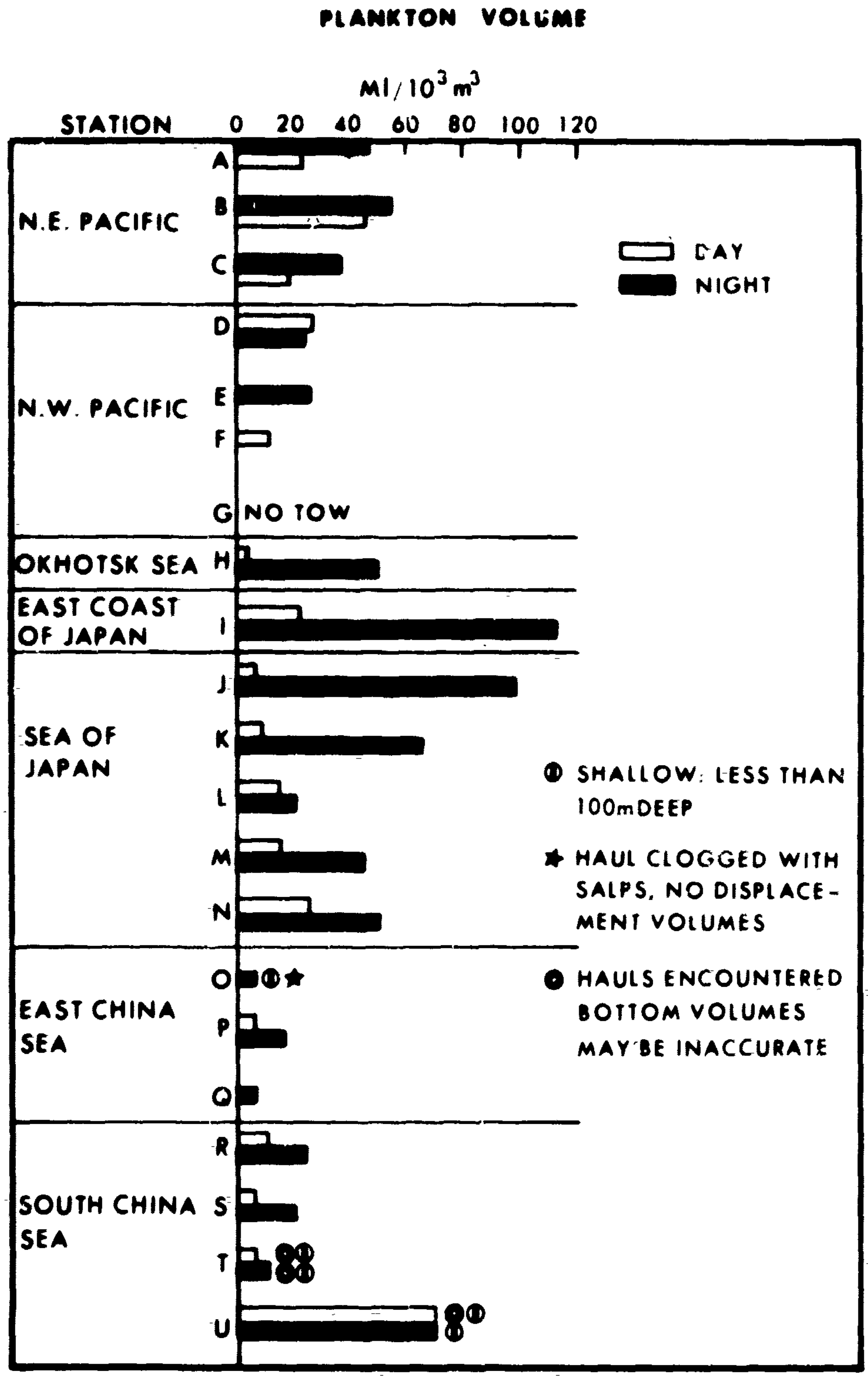


Figure 8. Histogram of net plankton volumes for day and night hauls.

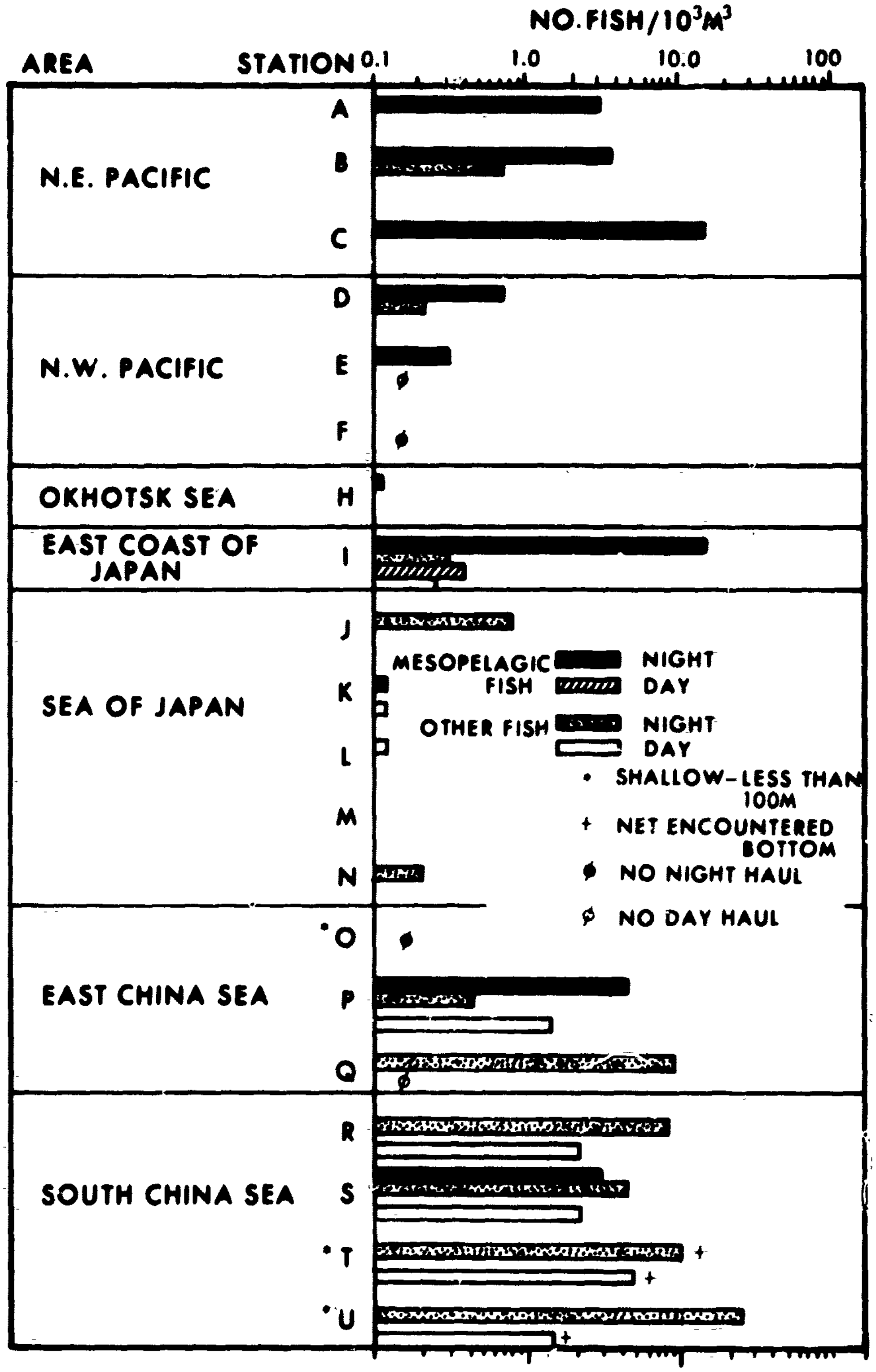


Figure 9. Mesopelagic and "other" fish concentrations for day and night net hauls.

1. NORTHEAST PACIFIC

- Transitional Domain Station A

  Overall, few organisms were collected; euphausiids (krill) were the dominant plankton. A moderately large number of mesopelagic fish ($3.3/10^3m^3$) were collected, of which about 50% were Myctophidae and the rest were from other families.

- Central Subarctic Domain – Stations B and C

  Relatively large numbers of secondary plankton, particularly medusae, were captured. Primary plankton was slightly more abundant than in the Transitional Domain, with very large numbers of Decapods (ocean shrimp) taken in the day haul ($497/10^3m^3$) on Station B. High concentrations of mesopelagic fish, mostly the Myctophid, *Stenobrachius leucopsaurus*, were recorded, particularly on Station C, at which site the night haul yielded 16.6 fish/10^3m^3 (the highest concentration observed during the cruise).

2. NORTHWEST PACIFIC Stations D, E, F, and G

Secondary plankton was abundant, with moderately high concentrations of medusae and chaetognaths and the first record of copepods. Euphausiids were relatively numerous and mesopelagic fish were sparse (less than $1/10^3m^3$).

3. SEA OF OKHOTSK – Station H

Large numbers of Euphausiids and very little other plankton were taken. Only one fish, a Bathylagid, was taken in the night haul.

4. EAST COAST OF JAPAN Station I

Moderate numbers of secondary plankton and euphausiids were collected. The largest displacement volume of fish observed during the cruise (45.4 ml/10^3m^3) resulted from the night haul on Station I; the majority of the catch was the Myctophid *Diaphus theta.*

5. SEA OF JAPAN Stations J, K, L, M, and N

Numerous primary and secondary plankton were collected. The concentrations of chaetognaths, copepods, amphipods, mysids (opossum shrimp) and euphausiids were the largest, on average, for any area of the cruise. Conspicuously absent from the catch was any form of mesopelagic fish. Only a few unidentified larval and juvenile epipelagic fish were taken. With the exception of Station L, the plankton volumes were relatively high.

6. EAST CHINA SEA Stations O, P, and Q

Plankton volumes were the lowest of the cruise; only traces of secondary plankton and small numbers of euphausiids were taken. A variety of mesopelagic fish were caught on Station P and a relatively large number of "Other" larval and juvenile fish were taken on Station Q.

7. SOUTH CHINA SEA Stations R, S, T, and U

Only traces of primary and secondary plankton and a few mesopelagic fish (from Station S) were netted in this area. There were, however, large numbers of larval and juvenile fish taken, particularly on Station U with 23.1 fish/$10^3 m^3$ caught. The net encountered the bottom on Stations S and T, which made accurate counts of captured organisms difficult.

ACOUSTIC MEASUREMENTS

Values from both 3 and 12 kHz day and night column strength measurements are shown in figure 10. The mean column strength values are shown; the number of observations and their standard deviation (σ) are also given.

From the data summarized, no set pattern applicable to all areas is evident. Day/night and area to area variability are high, particularly in the Sea of Japan, at which site values ranged from −46.0 to −77 dB. The highest measured column strength was the night 12 kHz value (−45 dB) observed on Station P in the East China Sea. Generally, the values from night measurements exceeded those from the day at a given frequency; but in four cases the converse was true. Column strength values at 3 kHz exceeded 12 kHz values in the Northwest Pacific, the Sea of Okhotsk, and on Stations J–M in the Japan Sea. The opposite was true for Station N and in the East and South China Seas. Column strengths were moderate in the Northwest Pacific and off the East Coast of Japan, relatively low in the Sea of Okhotsk, and from very low to moderate in the Sea of Japan.

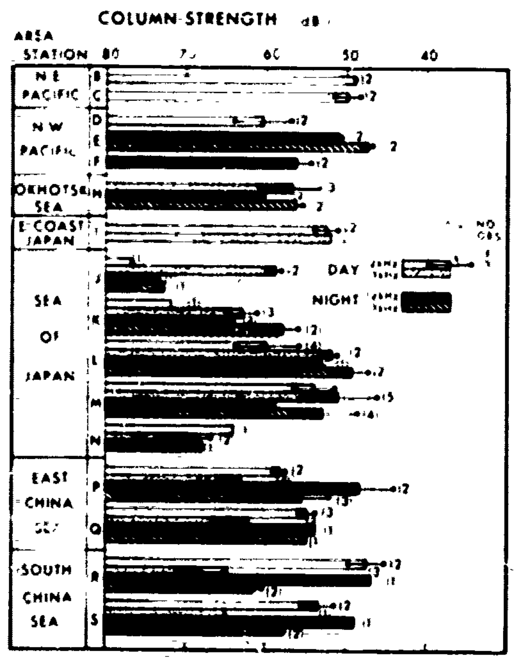


Figure 10. Measured day and night 3 and 12 kHz column strength values. Mean values and standard deviations (σ) are given

DISCUSSION

The primary mission of FASOR II was to collect acoustical, sonar-related data; this fact combined with the considerable number of other tests on the ship schedule allowed only minimal time for biological sampling. In addition, some sections of the echo sounder record are missing or inadequate because of unfavorable recording conditions or use of the recorder for purposes other than scattering observations. Noting these limitations, however, a general discussion of the biological and physical environment and the acoustical characteristics as related to scattering layers and spurious acoustic targets observed in the North Pacific Ocean is presented.

ACOUSTIC SCATTERING

Large Echo Groups (LEGs)

Large echo groups are discrete acoustic phenomena that are recorded on high-resolution 12 kHz echo sounders as individual reflections with distinct upper outlines that are hyperbolic in shape (see figure A-36); from a cruising ship, the recorded form typically resembles an inverted "V". The geometry of the situation which producesd such traces has been documented.[19] Large echo groups also appear as long serrate bands, typically in records from a drifting ship (see figure A-13), or as layer-like formations (see figure A-32).

The importance of LEGs as false targets has not been fully determined. Their frequent occurrence in many areas of the Pacific, combined with a few high values from scattering measurements, indicates that LEGs may be important causes of false targets as identified by echo locating systems or responsible for significantly increasing sonic reverberation levels in some areas.

The distribution of large echo groups (see figure 1) implies a near-shore characteristic. If LEGs are large solitary organisms or schools of fish, as generally assumed, their predominance in the biologically-rich neritic or near-shore regions is understandable. It has been observed[20] that while only 7.6% of the area of the world ocean is in the neritic zone approximately 86% of the world's marine fishes are caught in this zone. In a very general sense, then, the distribution of LEGs and the major concentrations of commercially important fish are coincident.

In figure 4 the mean 12-hour day/night LEG concentrations graphically show the patchy and highly variable nature of LEG distribution. Part of the variability is due to the fact that LEG density (*i.e.*, number per unit volume of insonified water) was frequently higher on station than in adjacent areas. The higher LEG density on station could be from either an increased equipment sensitivity,[21] which would result from a decrease in noise while the ship was drifting, or from errors in the calculation of insonified volumes as the result of an assumed 1 knot drift rate or failure to note station-keeping movements of the ship. In any case, further study of this phenomenon should be accomplished before the accuracy of any predictive model based on LEG observations of the type discussed here can be assured.

The highest LEG densities were observed in the Sea of Japan and the Sea of Okhotsk, with mean day and night values exceeding 0.1 LEG/$10^6 m^3$. On the other hand, only a few LEGs were observed in the Northeastern Pacific and the mean density there, less than 0.001

LEG $10^6 m^3$, was more than two orders of magnitude less. Other areas showed intermediate densities. The differences between the day and night densities and variability are given in Figure 11 in the form of confidence intervals. In all areas, except the Sea of Japan, mean day LEG densities were higher during the day than at night. Statistically, however, only the Northeast Pacific, the East Coast of Japan and the South China Sea show significantly higher day than night LEG densities at the 95% level of confidence. The Sea of Japan, which was anomalous in several characteristics, is the only area with a significantly higher night LEG density than day.

The greater the day/night LEG density difference, the higher the probability of a diel behavioral pattern such as vertical migration or nocturnal school diffusion. Diel behavior of LEGs is also indicated in Figure 12, which describes the percent frequency of occurrence of LEGs over a 24-hour period in several areas. In the South China Sea, diel behavior was indicated by the absence of LEGs between 2100 and 0300 and maximum percent observation at 1700 and 1800. Conversely, the Sea of Japan showed nearly no diel differences in occurrence of LEGs; all values were 50% or above. The Northwest Pacific displayed a slight trend toward a diel pattern, but some LEGs were observed during all hours. Figures 13, 14 and 15 display LEG depth distribution in relation to scattering layers as generalized for specific areas. Figure 13 demonstrates that the diel behavior exhibited by LEGs in the South China Sea was in the form of vertical migration and probably school diffusion between 1900 and 0400. The migrations of both the DSL and LEGs coincided closely in time and depth. It has been suggested[21] that discrete targets which migrated with scattering layers in the southern Pacific were predators which fed upon DSL organisms. The depression of the depth of deepest occurrence of LEGs in the Sea of Japan around midday (see figure 14) may be indicative of partial migration by a particular species or an interactive behavioral pattern by two or more species.

In the northwestern Pacific the majority of the LEGs remained just below the scattering layer, which was also the depth of the thermocline (see figure 15). This phenomenon may be the result of the low near-surface temperatures (below 0°C) in the region. Figures A-11 and A-12 show how both LEGs and diffusive scattering tended to remain below the sharp positive thermocline (see figure2) in the vicinity of Station F. In other areas, though less information is available, some trends are noticeable. In both the Western Pacific and the East Coast of Japan, LEGs tended to form layers that migrated similarly to the scattering layers, as shown in Figures 16 and A-15. The density of LEGs was quite high near the East Coast of Japan and the influence of the combined physical factors upon the biological distributions in this zone of transition appears to warrant further investigation. The East China Sea exhibited some areas with high densities of LEGs and a large area around Station P, in which no LEGs were observed; this further exemplifies the sporadic nature of echo group occurrence.

In general, there appear to be large geographical area differences in temporal and distributional LEG characteristics. This observation reaffirms the importance of studying biological and related acoustical data in the context of geographical areas of similar physical and, perhaps, chemical characteristics.

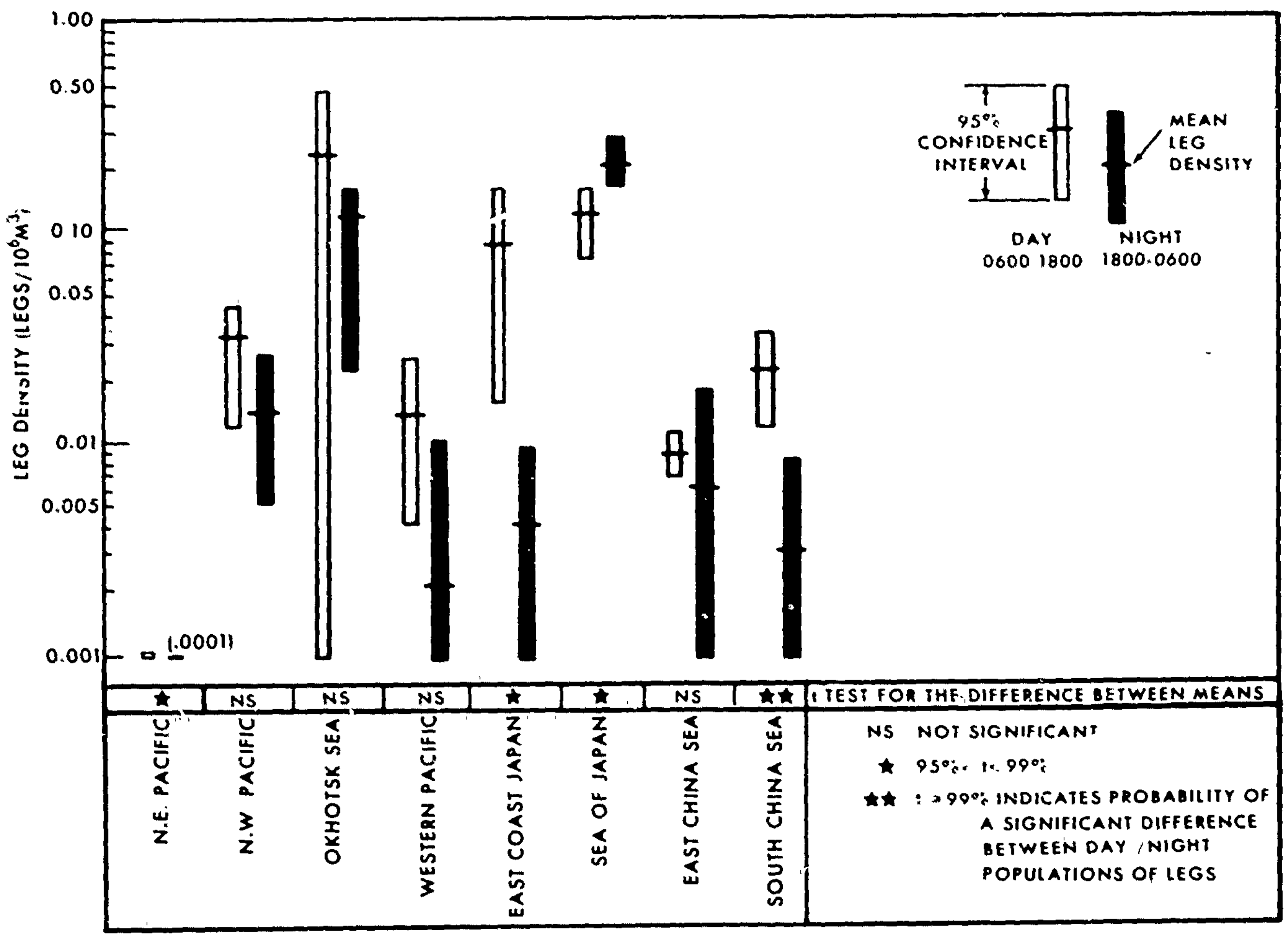


Figure 11. Comparison between day and night LEG densities for all geographical areas (means, confidence interval and significance probabilities are given).

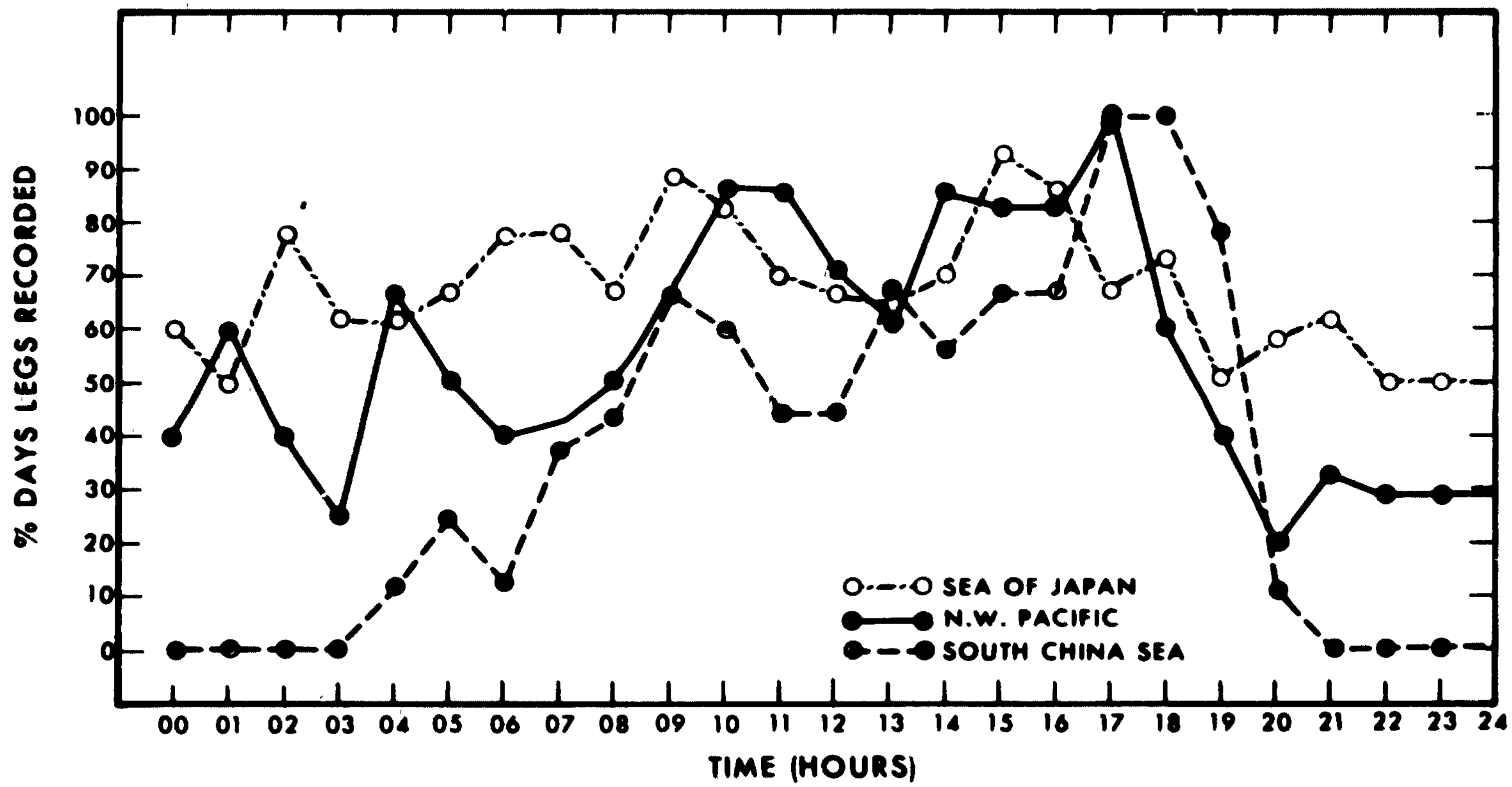


Figure 12. Temporal LEG frequency distribution for three diverse areas (number of days of recorded LEG observations at specific hour total number of recorded days).

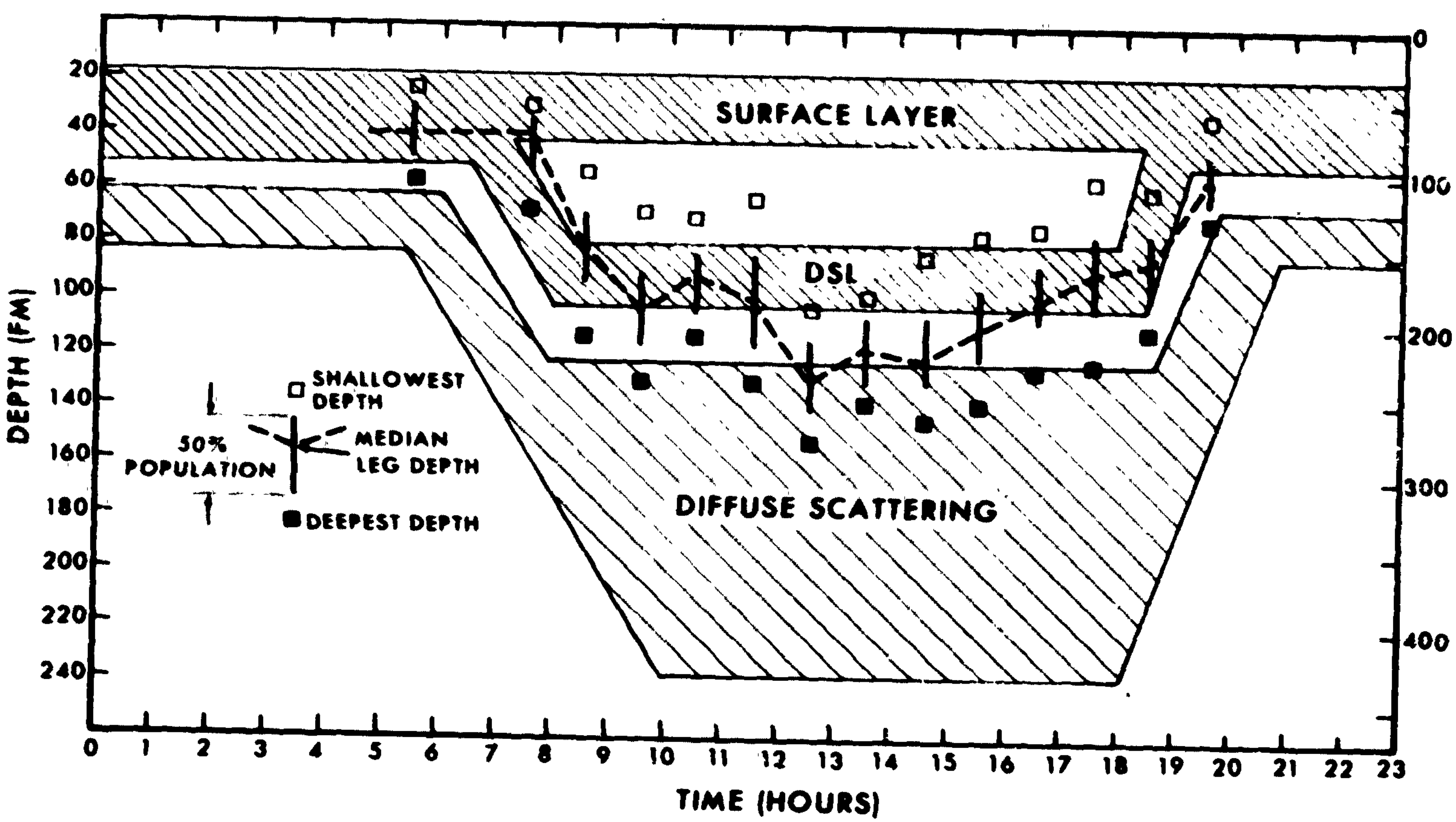


Figure 13. Temporal LEG depth distribution (dashed line) and diagramatic scattering layer configuration of the South China Sea.

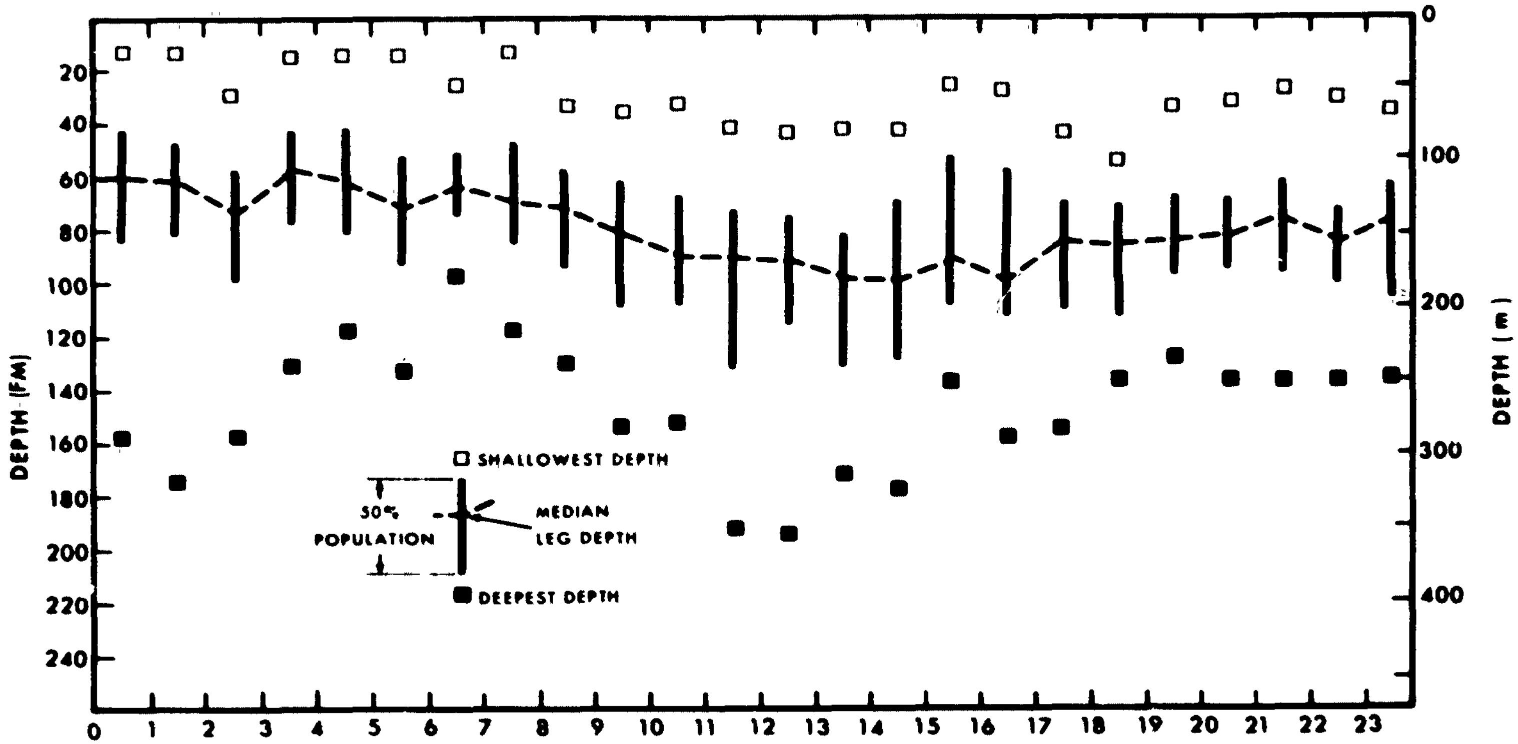


Figure 14. Temporal LFG depth distribution (dashed line) of the Sea of Japan (no observed 12 kHz scattering layers).

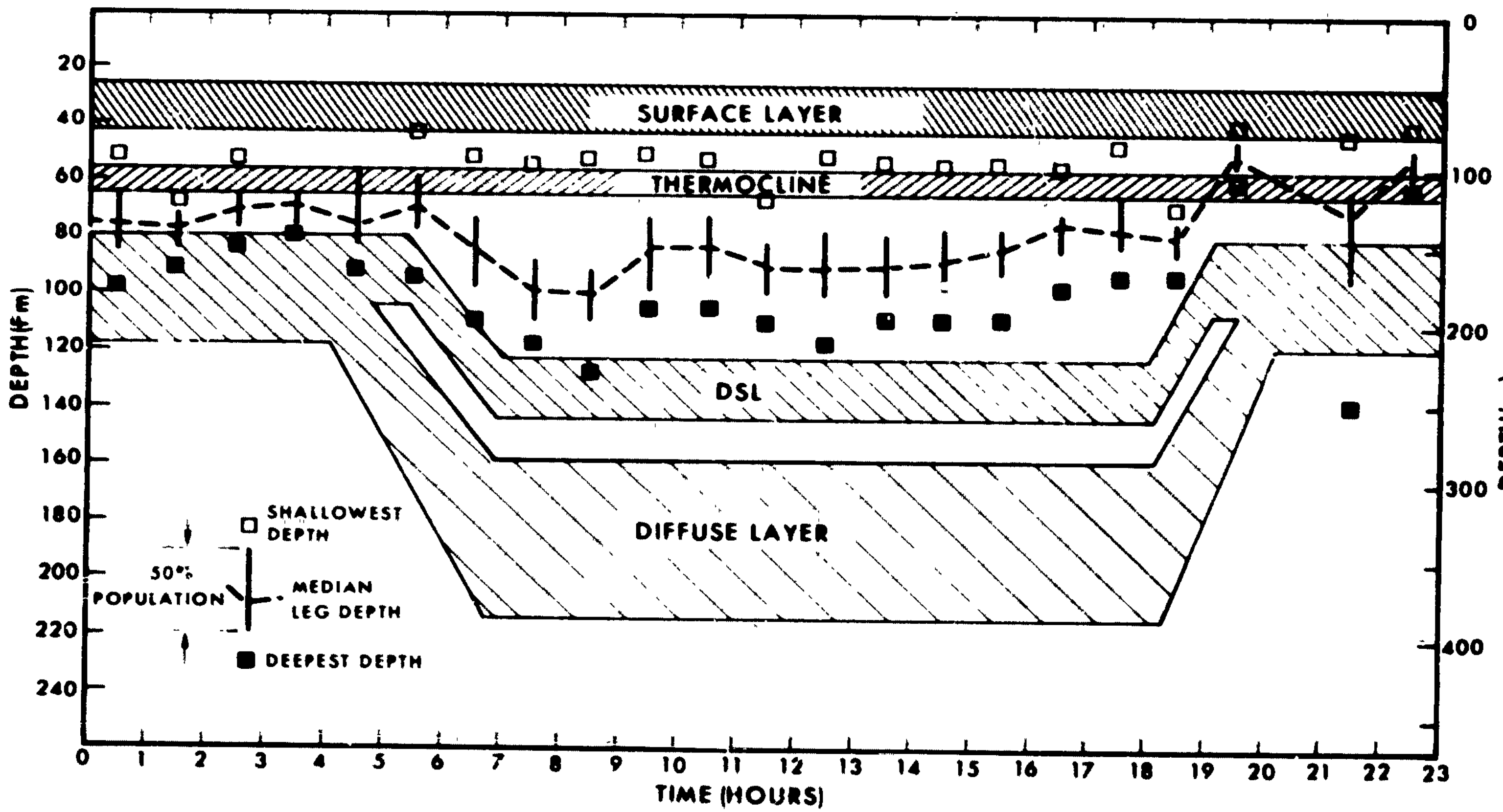


Figure 15. Temporal LFG depth distribution (dashed line) and diagrammatic scattering layer configuration of the N. W. Pacific

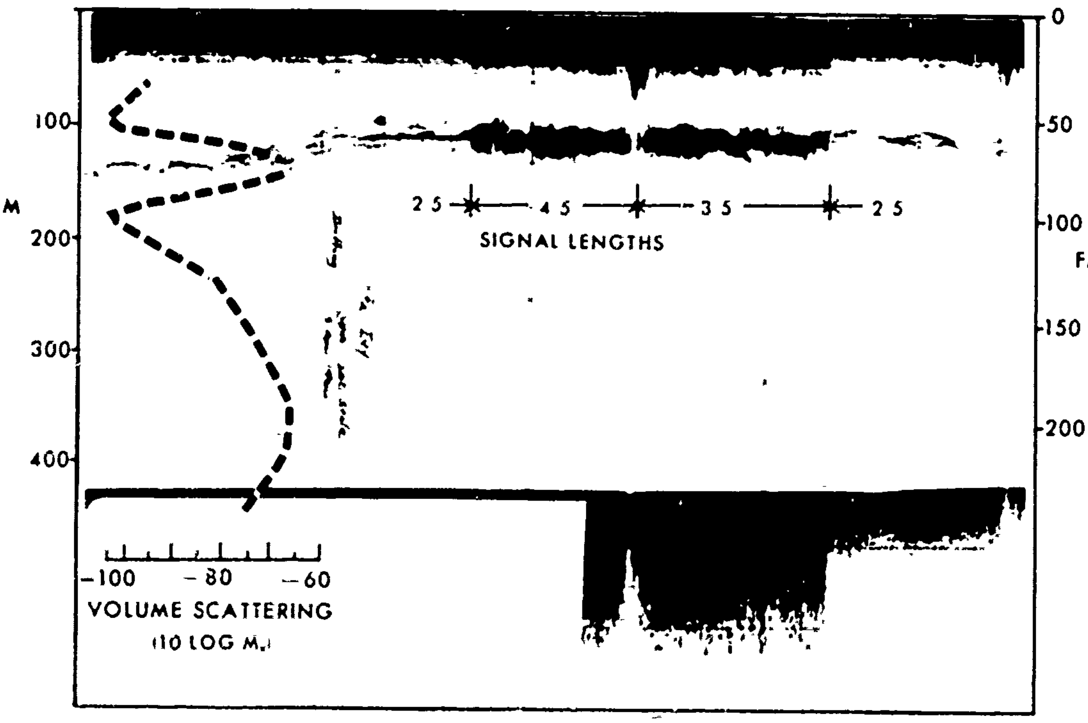


Figure 16. Twelve kHz volume scattering in relation to echogroups and scattering layers on Station I off the East Coast of Japan. The effect of altering signal length is also demonstrated. (Photo 1200, acoustic measurement 1400, 5 Apr 1966.)

DEEP SCATTERING LAYERS (DSL)

Scattering layers, as identified by 12 kHz echo sounder records, were observed in nearly all regions during FASOR II, with the exception of a major portion of the Sea of Japan where layers were absent. Appendix A includes photographs of echo sounder records of day and night scattering patterns for most stations. In general, there appears to be a negative relationship between the amount of scattering in the form of layers and the occurrence of LEGs. In the Northeast Pacific, the site at which scattering was particularly pronounced and complex, there were few LEGs. Conversely, there were high numbers of LEGs in the Sea of Japan, but little diffusive scattering except near Station N and the Korea Strait. Although other areas had scattering layers and LEGs together in varying proportions, exact correlations are difficult to determine.

There is an apparent relationship between physical domain (water mass) characteristics and scattering layer configuration. The most obvious example is the transformation from complex, multilayered scattering in the Transitional Domain to simple, generally single-layered deep scattering in the Central Subarctic Domain (see figure 7). A comprehensive study of existing sound scattering layer records has been made with the Pacific area divided into 17 "natural biogeographical" areas based on layer distribution and configuration.[22] These areas were geographically similar to those delineated in this report and the scattering layer configurations were generally compatible, particularly for the Northwest Pacific area. Previous studies of the plankton and small nekton in the area of transition between the

Transitional Domain and the Central Subarctic Domain of the Northeast Pacific,[23, 24] which describe physical characteristics influencing biological populations, may partially explain the variation in scattering characteristics observed between the two water masses. Thus, populations of organisms in different water masses may have different migratory behavior, depth distribution, swimbladder morphology, etc. Such differences may be manifest in the number, depth, intensity or migratory pattern of scattering layers observed in the water masses.

The layers of the Central Subarctic Domain also differed from those of the Western Subarctic Domain, where the scattering layers became more numerous and complex. As previously mentioned, the negative thermocline in the Northwest Pacific apparently restricts the vertical distribution of both LEGs and scattering layers, presumably by acting as a barrier to the upward migration of the causative organisms.

The Western Pacific showed fairly broad scattering layers and the East Coast of Japan had similar layers closer to the surface (see figure 16) with an additional small LEG layer. The East and South China Seas generally had dense shallow layers and frequently deep, diffusive layers with some intermediate-depth scattering.

Physical and chemical characteristics of water masses are major factors governing species distribution and regional population composition in the sea.[25] They also can be expected to affect the vertical distributions and migrations typical of the DSL in a particular region. The limited data from FASOR II indicate a relationship exists between LEG distribution, scattering layer patterns, and the physical characteristics of water masses. An understanding of this relationship is fundamental to reliable prediction of the acoustical/biological environmental interactions affecting echo location devices in a particular area of the open ocean.

BIOLOGY

General patterns of biological abundance and distribution are identifiable in the data summarized in Table 4. The regional occurrence of fishes is summarized in Table 5 and the specific fish catch for each haul is detailed in Appendix B. At the only station taken in the Transitional Domain, the overall plankton concentration was low. The concentrations of zooplankton increased in the Central and Western Subarctic Domains and the highest densities occurred in and near the Sea of Japan. In the East and South China Seas, very little primary or secondary zooplankton was taken, but relatively large numbers of fish were netted.

Secondary Plankton

Specifically, secondary plankton of medusae were almost exclusively collected in the cold waters of the Subarctic region, whereas chaetognaths (arrow worms) were nearly universally collected, except on the shallow-water station T; chaetognath concentrations were highest in the Sea of Japan. Although copepods are generally considered ubiquitous in the ocean, the trawl used on FASOR II took them only in the Western Subarctic Domain, off the East Coast of Japan, and in the Japan Sea. The absence of copepods in hauls from

other areas may be that small copepods are lost through the net mesh during a haul[26] or that they exhibited avoidance movements as the net approached.[27] The concentrations of amphipods were greatest from the Sea of Okhotsk through the Sea of Japan; smaller numbers were caught in other areas.

Specific members of the secondary plankton typically have restricted distributions and thus are "indicator species" for certain water types.[25] The overall biological program executed on FASOR II did not emphasize capture of the smaller organisms; the gear employed selectively sampled for larger organisms and the sorting of the samples only identified plankton as to general type and not to species. This treatment should not affect the overall conclusions concerning acoustical and biological correlates, however, because recent data indicate that secondary plankton is responsible for no more than 1% of the total deep-water scattering in the range from 3 to 100 kHz.[18] Although, in many respects, it is relatively easy to obtain good samples of copepods and the like, their relationship to oceanic reverberation has not been systematically defined and thus at present even the best obtainable data on secondary plankton would have little interpretive or predictive value in an acoustical context. The data emphasize, however, the biological variability which may exist between physically-defined water types.

Primary Plankton

Euphausiids were by far the most abundant category of primary plankton taken on FASOR II. Their concentrations were particularly high in the Sea of Okhotsk, off the East Coast of Japan, and in the Sea of Japan. The Northeast and Northwest Pacific areas had intermediate euphausiid concentrations and, again, the more southern marginal seas had very low densities. Considerable numbers of decapods were taken in the Central Subarctic Domain. On Station B, extremely high decapod concentrations were of the single genus *Sergestes*, with the vast majority taken in the day haul. According to previous studies,[28] *Sergestes* migrate vertically and night catches far exceed day catches in near-surface waters off the Oregon coast. The situation seen at Station B may indicate a reverse diel migratory pattern, or it may simply reflect small-scale patchiness in the distribution of the organism. Mysids, the third category of primary plankton, were infrequently taken; the major concentrations occurred in the Sea of Japan.

At frequencies above 30 kHz, primary plankton appear to be the predominant cause of scattering, and crustaceans in particular are increasingly important in more northern regions and at higher frequencies. However, at 20 kHz both primary plankton and fishes with swim bladders are known to contribute to the scattering.[18] The distribution of Pacific euphausiids have been summarized[29] and show that species typically associate with particular water types. Manpower limitations prevented identification of FASOR II euphausiids to species, so that their value in a zoogeographic sense is limited. The data from the primary plankton, as with that from the secondary plankton, are again indicative of the biological variability associated with different water masses. Because it is typically larger than secondary plankton, primary plankton is less likely to be lost through the net mesh during a haul and more likely to successfully avoid capture by the approaching trawl; the magnitude of these processes and their effect on overall catch results has not been adequately assessed for

the Tucker trawl. In general, however, it is probably easier to obtain valid samples from primary plankton populations, such as euphausiids, than it is from populations of swim bladder fish which represent scattering below 10 kHz.[18] From a biological standpoint, the fish primary plankton relationship is often less obscure than that between the fish and secondary plankton, but a rationale for utilization of primary plankton data in the context of predictive oceanic acoustics has not been developed. Such a rationale would be particularly useful in determining the geographic extent to which acoustical information from a particular location could be applied. For the time being, such estimates must be derived from data on the fish themselves.

Fish

Fish with gas-filled swim bladders are generally accepted as the significant scatterers of midfrequency (1–15 kHz) sound in the ocean, and mesopelagic fishes particularly those from the families Myctophidae (Lanternfishes), Gonostomatidae (Lightfishes) and Sternoptychidae (Hatchetfishes) have long been associated as probable sources of volume reverberation in the deep sea.[5,6,30,31,32] Much of the work that relates the characteristics of deepsea fish and their populations to resonant volume scattering is based on biological observations of two investigators[33,34] and utilization of acoustical considerations by others.[35,36] Such information has been synthesized[37,38] and summarized.[18] Detailed measurements of the acoustical properties of scattering-layer fish are now being emphasized to better reconcile scattering theory with observations made at sea.[39,40] Both acoustical and biological information have been utilized to formulate a general predictive model in which known mesopelagic fish populations with specific swim bladder sizes can be used to predict column scattering strengths at different frequencies for various regions of the ocean.[41]

Of the 570 total fish taken by trawling, 265 (46.5%) were mesopelagic forms and 305 (53.5%) were "other fish," principally young forms of genera typical of the near-surface zone. forty-six percent of the "other fish" were from hauls made in shallow water. With one exception, the fish taken in day hauls were from the "other fish" categories. Haul 14, a day haul on the East Coast of Japan, took five mesopelagic fish from 3 genera along with a single larva of unspecified type; the haul had the greatest sampling depth of any day haul. Ninety percent of the mesopelagic fish and likely most of the "other fish" collected had swim bladders. Fish typically were netted in hauls which included the general depth interval of observed scattering layers, especially at night. Mesopelagic fish, generally, and myctophids and gonostomatids, in particular, are scarce in the Sea of Japan.[42] No mesopelagic fish were taken in the Sea of Japan and scattering layers, as indicated by 12 kHz echograms (see figure 7), were virtually absent before Station N. These observations, along with the apparent correlation between column strength and fish catches at night (see below), indicate that mesopelagic and certain other types of fish contributed significantly to the mid-frequency volume reverberation and scattering measured during the cruise.

Over 85 percent of the mesopelagic fish sampled were taken in the first 15 hauls of the cruise. Four myctophid and a single gonostomatid species accounted for 79 percent of the mesopelagic fish taken and, with the exception of the myctophid *Ceratoscopelus warmingi* which has a tropical to subtropical habit,[43] these species had distributions largely

restricted to Subarctic or Transitional waters of the North Pacific.[44] The most abundant mesopelagic species with swim bladders taken were as follows:

1. *Stenobrachius leucopsaurus* (90 fish from 5 hauls) comprised the majority of fish taken on Station B, 87 percent of those taken on Station C, and thus were the most numerous component of the mesopelagic fish population sampled in the Central Subarctic Domain. Although its numbers were greatly reduced, *S. leucopsaurus* also constituted a major component of the catch on Stations D and E in the Western Subarctic Domain. None was taken in the Transitional Domain (Sta. A), although the species is endemic to the subarctic and transitional waters of the north Pacific.[44]

2. *Diaphus theta* (80 fish from 4 hauls) were particularly abundant on Station I off the East Coast of Japan and comprised 69 percent of the catch. The species was also taken, although in lesser numbers, at Stations B and C in the Central Subarctic Domain. The taxonomic status of this genus is quite unsettled[45] and has been called *D. theta* by those who have identified this species throughout the subarctic and transitional waters of the north Pacific.[44] The species seems particularly abundant in the California Current and in the Northwest Pacific, at which sites great numbers are known to occur near the shores of Japan.[46]

3. *Gonostoma gracile* (17 fish from 3 hauls) were taken in moderate numbers off the East Coast of Japan and also in the East China Sea. The species is usually found in the Northwest Pacific, although it is also taken south of Japan to 18°N.[44]

4. *Lampanyctus ritteri* (13 fish from 1 haul) were collected at Station A only and constituted 57 percent of the total catch. Typically, this species is taken only in the Transitional waters of the north Pacific.[44]

5. *Ceratoscopelus warmingi* (10 fish from 2 hauls) were taken at night in the East and South China Seas. It was the most abundant mesopelagic fish taken after the cruise left the Sea of Japan. As previously mentioned, *C. warmingi* is found in the warmer waters of the Pacific.

Of the mesopelagic fish lacking swim bladders, only the bathylagid *Bathylagus ochotensis* was taken in significant numbers (12 fish from 2 hauls), primarily off the East Coast of Japan.

On six stations (A, B, C, I, P and S) the nocturnal concentration of mesopelagic fish exceeded 1 per $10^3 m^3$ (Table 3). The maximum diurnal scattering strength (S_V) for these stations ranged from -66.5 to -84.5 dB, which is far below that given in previous theoretical studies[47] and which suggests that at least one swim bladder fish per $10^3 m^3$ would be sufficient to produce an S_V of -65 dB, presuming an ideal frequency-to-depth ratio for a particular size swim bladder. Another author[18,35] has suggested that as few as one swim-bladder fish per $10^4 m^3$ of water is sufficient to have a "significant effect" on scattering from a layer centered at 300 meters. The low values of S_V reported here, however, indicate that the swim-bladder populations encountered during FASOR II varied from the ideal conditions assumed by the above authors and that, at 12 kHz, significant resonant response from the swim bladders is lacking. Overall, the general correlation between night fish concentrations and column scattering strength (both day and night) was positive.

Whether or not the types and sizes of netted fish had the physical structure required to produce the observed acoustical conditions was not determined in this study. Such conditions as the occlusion of the swim bladders of older *S. leucopsaurus* and *D. theta*[34] or the diminutive size of the swim bladder relative to overall body size in *L. ritteri* will influence the quantity and quality of the sound scattered by these species. Hauls on stations in the East and South China Seas took many "other fish" (see Tables 4 and 5), none of which was identified or examined in detail. If an appreciable portion of these fish had gas-filled swim bladders, they may have been important contributors to the relatively high scattering levels measured on the southern stations. Unfortunately, mesopelagic and most larval fish are extremely delicate and notoriously difficult to maintain in captivity for more than a few hours. Thus, a clear definition of their exact acoustical characteristics is lacking. Given the limitations inherent in the program, however, the data prepared from fish encountered during FASOR II are both applicable and useful in an integrated biological/acoustical program.

ACOUSTIC MEASUREMENTS

Acoustic measurements made during FASOR II are comparable with those of previous studies.[9] There is generally good correlation between the depth of scattering layers on the 12 kHz echosounder records and the depth of measured volume scattering peaks. Figure 17, for example, shows the relationship between the layers recorded on the 12 kHz echo sounder and the diurnal acoustic measurements of scattering on Station B at the same frequency.

The range of column strength values is

$$\left(10 \log \int_{z_1}^{z_2} s_v dz\right)$$

where z is depth, z_1 and z_2 are, respectively, the upper and lower limits of the column and s_v is the antilog of scattering strength ÷ 10 for a cubic meter of water at a particular depth. These values are shown in Figure 10. Those values above -50 dB are considered "high," those between -65 and -50 dB are "medium," and those less than -65 dB are considered to be "low." The mean column strength was considered high only in the Northeast Pacific (Central Subarctic Domain), where only day 12kHz measurements were taken, and the South China Sea. Other areas which showed high individual station column strengths were the Northwest Pacific, the Sea of Japan and the East China Sea. The Northwest Pacific exhibited the only 3 kHz value above -50 dB. The Sea of Okhotsk and the East Coast of Japan were both in the medium range. Variability was great everywhere, particularly in the Sea of Japan which exhibited column strengths ranging from -77 to -48 dB.

As previously mentioned, acoustic measurements of diffusive scattering from scattering layers are well documented. On the other hand, acoustic measurements from biological aggregations, spurious targets called large echo groups, are rare. Although a single strong acoustic return from an assembly of echo groups with a peak volume scattering coefficient of -42 dB and an estimated target strength of 0 dB has been measured,[10] the strongest column strength measured on FASOR II was an afternoon 12 kHz value of -46 dB from Station R in the South China Sea. As shown in figure 18, the relatively high

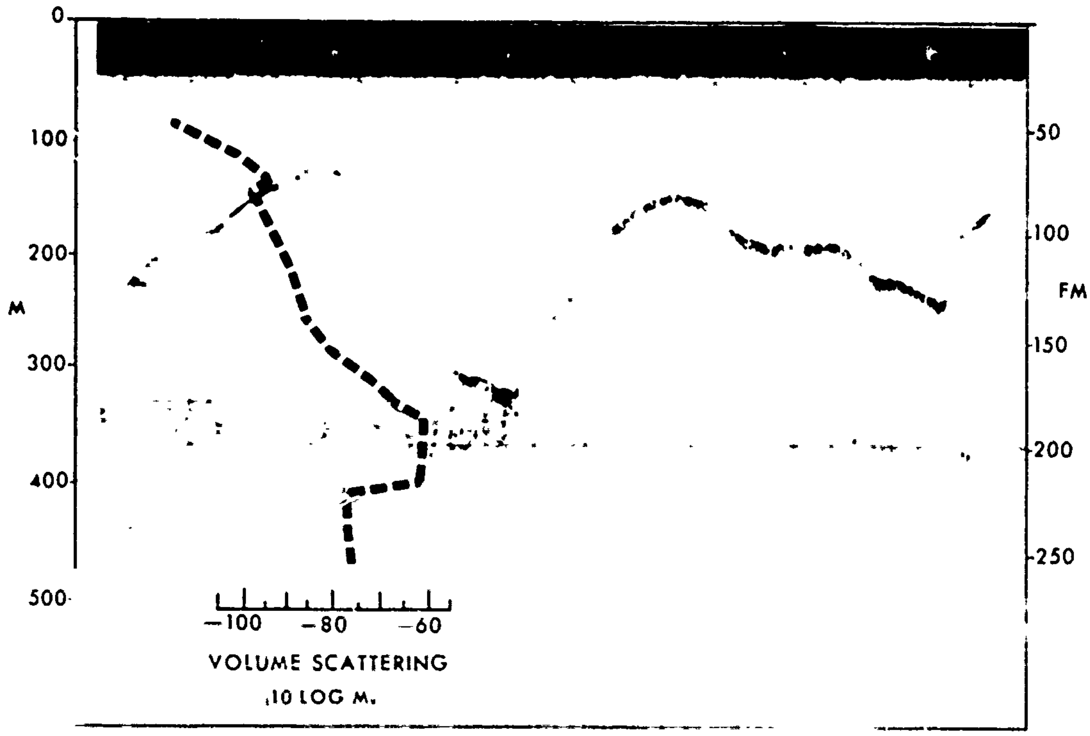


Figure 17 Twelve kHz volume-scattering measurement in relation to scattering layer on Station B in the N.E. Pacific. (Photo of 12 kHz PDR echogram, 1300, 13 Feb 1966.)

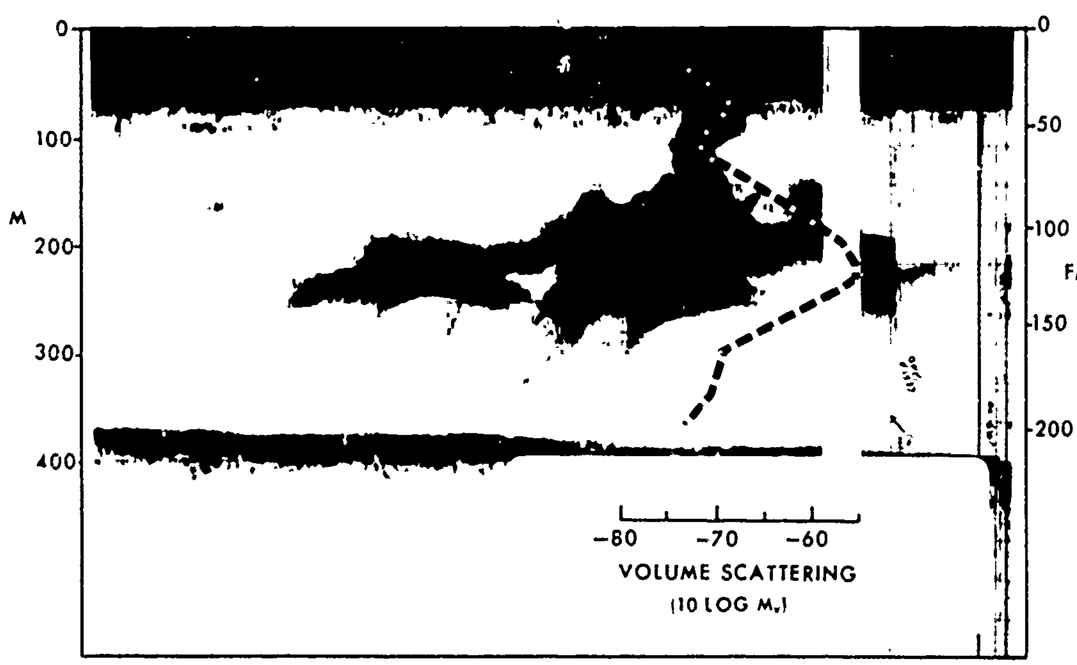


Figure 18 Twelve kHz volume scattering measurement, apparently from a LEG, Sta. R, South China Sea. (1600, 13 May 1966.)

scattering level was apparently due to a large cloud-like echo group with peak volume scattering of −54 dB. Exceptionally large echo groups, similar to the one shown in figure 18, were relatively common in the South China Sea. Another example is shown in Appendix A, figure A-36.

Because LEGs commonly occur throughout much of the Pacific (see figures 1 and 5), particularly near shore, and because they may cause both high column strengths and volume scattering peaks, they must be considered a significant factor in the operation of echo-locating systems. Specific areas in which LEGs might be significant acoustic scatterers are discussed below.

The Northeast Pacific (Central Subarctic Domain) had both high average column strengths and relatively high scattering peaks. LEGs were relatively rare in contrast to scattering layers which were common at the depth of peak acoustic scattering. This indicates that most of the measured scattering was caused by DSL organisms.

In a large portion of the Northwest Pacific (Western Subarctic Domain), the positive thermal gradient seemed to be an important factor governing acoustical reverberation; it apparently influenced the intensity and depth of both LEGs and scattering layers (see figures 15, A-11, A-12). On Station F, for example, the scattering layer and LEGs apparently did not migrate through the thermocline but concentrated below it; the depth of the observed peak of the 12 kHz scattering corresponded well with the depth of the layer and LEGs.

The Sea of Okhotsk had a large number of relatively small echo groups which probably had some effect on the peak scattering levels. As seen in figure 19, the acoustic peak at 12 kHz occurred when the group of targets was most dense, approximately 300 meters. Scattering layers were practically non-existent in this portion of the Sea of Okhotsk and therefore the LEGs are implicated as important causative factors for the scattering peaks and the moderate levels of volume reverberation observed.

Off the East Coast of Japan, scattering peaks were associated with layers at two depths. A layer of medium-sized echo groups (MEGs) and the first scattering peak occurred at 70 fathoms, and a deeper, thick DSL coincided with a broader acoustic peak between 140 and 220 fathoms (see figure 16). Figure 16 also shows the importance of signal length in the recording and interpretation of echo sounder records. When the signal length was changed from 2.5 to 3.5 msec, individual echo groups could no longer be resolved and what had been a layer of MEGs became a narrow dense scattering layer. Furthermore, the mid-depth scattering layer, which was not recorded at 2.5 msec, is evident at 3.5 msec. There appears to be little difference between recordings made at 3.5 and 4.5 msec. Because of this variability in recording sensitivity at different signal lengths, a decision should be made in advance as to which settings are most appropriate to the particular study in question.

The Sea of Japan was almost void of scattering layers. Figure 20 from Station J is representative of several of the stations in the Sea of Japan. It depicts a relatively low peak value of scattering in the same general depth interval as a concentration of LEGs. It is therefore likely that the highly variable volume reverberation measurements in the Sea of Japan were related to the numerous LEGs and MEGs of the region.

Reverberation levels in the East China Sea were moderate, with virtually no obvious scattering peaks. Both LEGs and scattering layers were discontinuous in time and space.

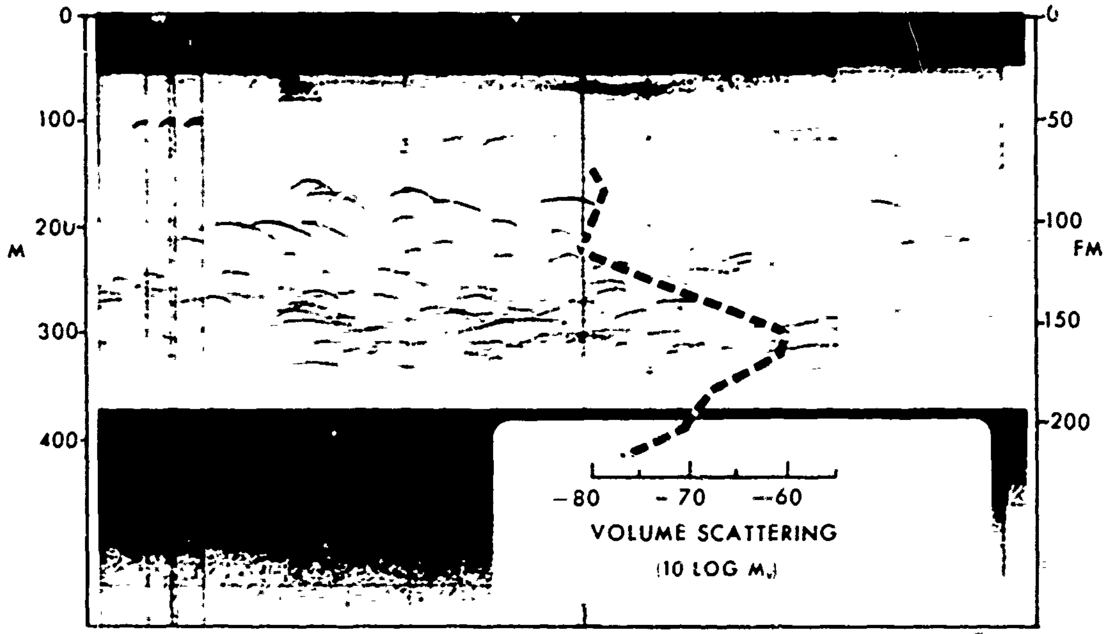


Figure 19 12 kHz volume scattering measurement, apparently from numerous LEGs, on Station H in the Sea of Japan. (Measurement 0160, echogram segment 0400, 15 Mar 1966.)

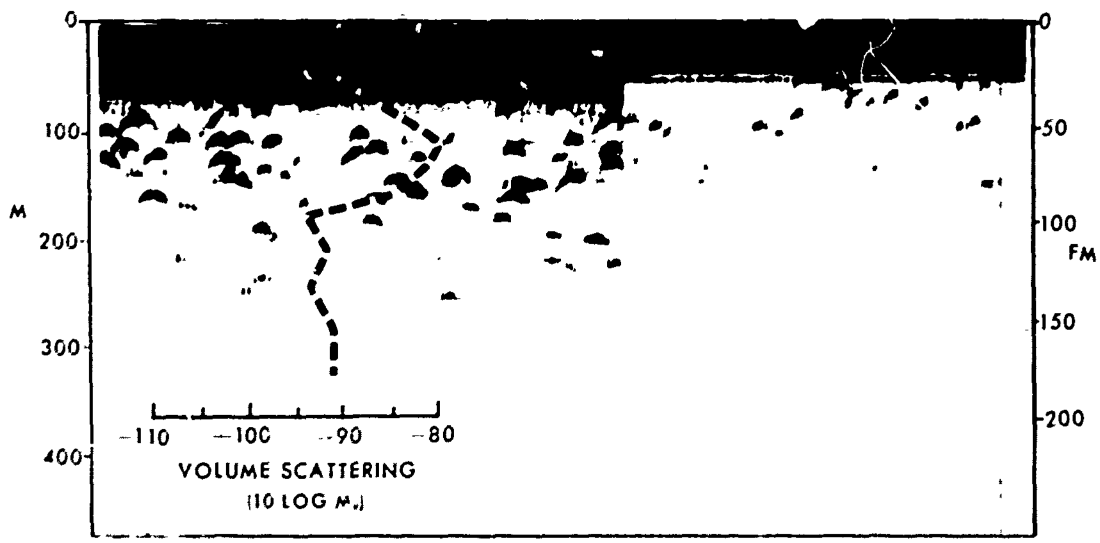


Figure 20 Twelve kHz volume scattering in relation to LEGs on Sta. 3 in the Sea of Japan. (Photo 2030 and acoustic measurement 2135, 10 Apr 1966.)

which may, in part, explain the lack of any distinctive reverberation peaks. The geographic location of Station P had been occupied during a prior cruise (Station I.).[9] The column strength values for the station from the two cruises are similar: a mean daytime value of -65 dB was measured in early May during FASOR II and a value of -61 dB had been measured in early July 1964.

In the South China Sea, the level of nocturnal scattering measured at 12 kHz was the highest of the cruise; 3 kHz scattering was moderate to low. With one exception, when a measurement apparently included a large group of scatterers (see figure 18), no significant scattering peaks were recorded in the South China Sea and only high, relatively constant column strengths were observed. This situation differs significantly from the Northeast Pacific at which site obvious scattering peaks, presumably caused by diffusive layers (figure 17), were the major components of the integrated column strength values.

Ultimately, this study and other similar biological/acoustical surveys seek information about the biological and physical factors which affect acoustical reverberation in the sea; so that realistic models can be developed to predict volume reverberation. Results with a preliminary model suggest that for a given area a rough estimate of the variation in column strength vs frequency may be made if the species of midwater fish and their approximate population density is known.[40,41] Conversely, the model implies that the column strength is roughly proportional to the population density of mesopelagic fish with swim-bladder radii between 0.05 and 0.5 cm. In this model, column strength decreases with frequency below 6 kHz and varies in magnitude for different oceanic regions. FASOR II measurements from the East and South China Seas seem to conform to the model. For stations north of 40°N and west of 170°E, however, column strength measurements at 3 kHz were significantly higher than those at 12 kHz. Apparent contradictions to this model were observed in the Northwest Pacific (Station E), the Sea of Okhotsk (Station H), and the Sea of Japan (Stations J, K, L, M). In all these areas few fish were netted, as shown in figure 21 (see figure 9 also). LEGs were abundant (figure 11; figure 21), and stations were within 150 miles of the shore. These factors, among others, may have contributed to the elevation of the 3 kHz column strength values relative to the 12 kHz values in the above areas. Because high LEG concentrations may indicate the presence of large fish in appreciable numbers, it is possible that more fish are nearer resonance at 3 kHz than at 12 kHz in these areas. In addition on the stations at which 3 kHz column strength exceeded that at 12 kHz, scattering layers were faint or nonexistent on the 12 kHz echograms (see figure 7). These observations suggest that preliminary models[40,41] are valid for peak scattering levels caused by small, layering organisms. However, in other areas that exhibit sporadic scattering layers, high LEG concentrations, and scattering layers dominated by larger organisms, other models will have to be developed and appr ed; this appears to be the case particularly in near-shore areas.

STATISTICAL CORRELATIONS BETWEEN BIOLOGICAL AND ACOUSTICAL DATA

To determine if potential relationships exist between various conditions observed or measured during FASOR II, Pearson product-moment correlation coefficients[48] were calculated for various combinations of data assembled either by individual station or for separate oceanic regions. The coefficients are indicative of the intensity of the relationship between two variables. The correlation coefficients and significance probabilities for various day/night combinations of acoustical and biological data are given in Table 6.

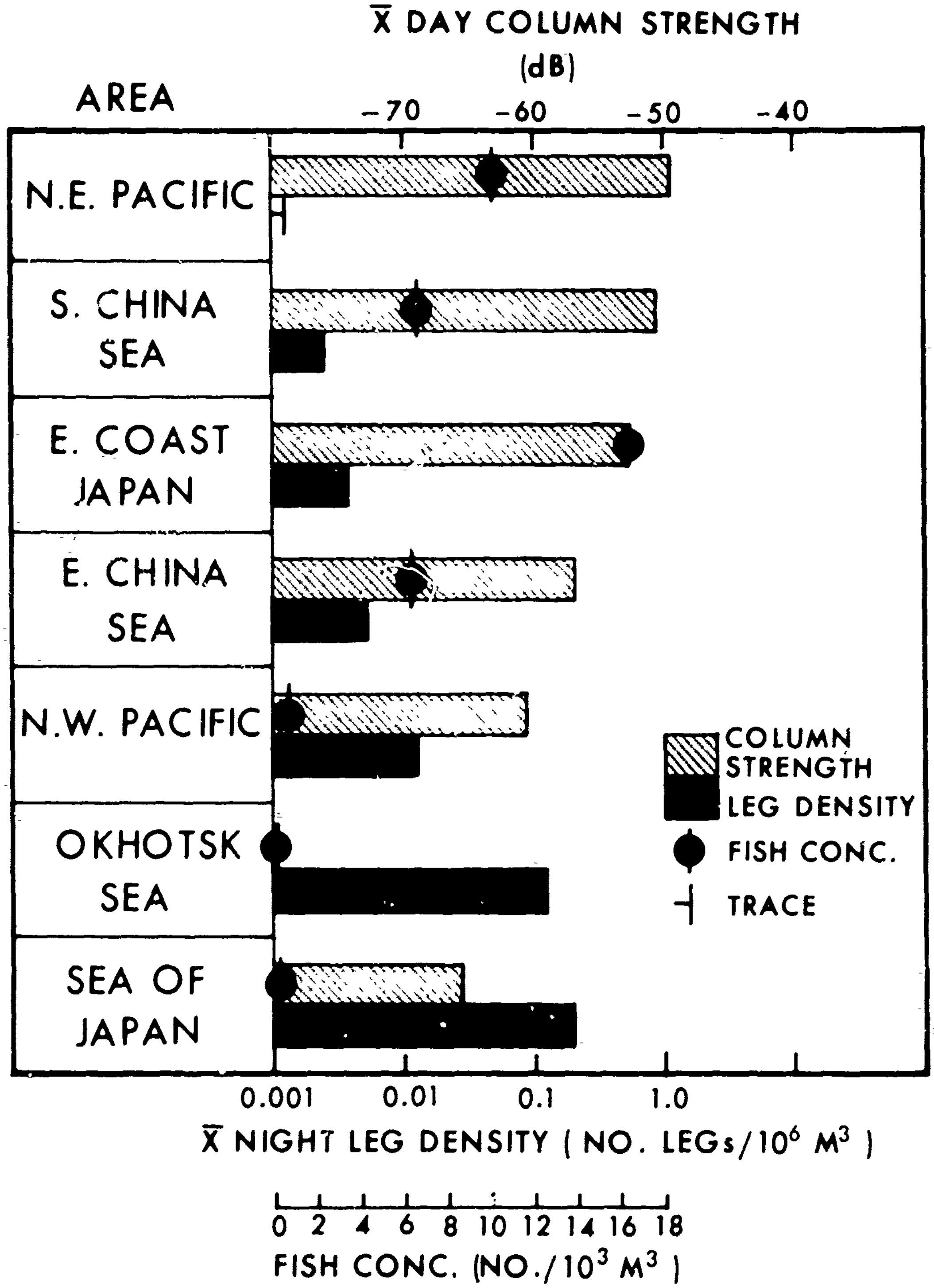


Figure 21. Summary, by area, of mean diurnal 12 kHz column strength, nocturnal LEG density (number per unit volume of ensonified water) and nocturnal fish concentration (number per unit volume of water filtered). Few LEGs were recorded in the N.E. Pacific; their density is only noted ("Trace") and not accurately depicted.

Table 6. Correlation Coefficients and Significance Probabilities for Various Acoustical and Biological Parameters

Correlation Day vs Day	Correlation Coefficient	Degrees of Freedom	Significance Probability
Column Strength: 3 kHz vs 12 kHz	-.058	8	NS
12 kHz column strength vs plankton volume	.393	9	NS
3 kHz column strength vs plankton volume	.071	9	NS
Day vs Night			
Column strength: 3 kHz vs 3 kHz	.348	7	NS
Column strength: 12 kHz vs 12 kHz	.860	7	<.01
12 kHz column strength vs Mesopelagic fish	.410	10	NS
3 kHz column strength vs Mesopelagic fish	.332	9	NS
12 kHz column strength vs total fish	.591	10	<.05
12 kHz column strength vs total fish*	.798	4	NS
12 kHz column strength vs total fish+*	.909	3	<.05
12 kHz column strength vs LEG concentration	-.193	9	NS
12 kHz column strength vs LEG concentration*	-.910	3	<.05
3 kHz column strength vs LEG concentration*	.303	3	NS
12 kHz column strength vs Euphausiid concentration	-.579	11	<.05
3 kHz column strength vs Euphausiid concentration	.447	9	NS
12 kHz column strength vs plankton volume	-.370	11	NS
12 kHz column strength vs plankton volume*	-.198	3	NS
3 kHz column strength vs plankton volume	.388	9	NS
3 kHz column strength vs plankton volume*	.928	3	<.05

* Area means

\+ minus east coast of Japan

\# Sea of Japan only

$ Stations other than the Sea of Japan

Table 6. (Continued)

Correlation Night vs Night	Correlation Coefficient	Degrees of Freedom	Significance Probability
Column strength. 3 kHz vs 12 kHz	.396	8	NS
Column strength: 3 kHz vs 12 kHz#	.962	2	<.05
Column strength: 3 kHz vs 12 kHz$	-.720	2	NS
12 kHz column strength vs plankton volume	-.896	9	<.001
3 kHz column strength vs plankton volume	-.692	8	<.05
12 kHz column strength vs plankton volume*	-.862	3	NS
3 kHz column strength vs plankton volume*	-.083	3	NS
12 kHz column strength vs total fish	.592	9	NS
3 kHz column strength vs total fish	-.100	8	NS
12 kHz column strength vs LEG concentration	-.193	9	NS
12 kHz column strength vs LEG concentration*	-.935	3	<.02
3 kHz column strength vs LEG concentration	.133	7	NS
3 kHz column strength vs LEG concentration*	.330	3	NS
12 kHz column strength vs total fish concentration*	.845	3	NS
Total fish conc. vs LEG conc.	-.206	14	NS
Total fish conc. vs LEG conc.*	.630	5	NS
12 kHz column strength vs Euphausiid conc.	-.649	9	<.05
12 kHz column strength vs Euphausiid conc.*	-.917	3	<.05
3 kHz column strength vs Euphausiid conc.	.165	8	NS
3 kHz column strength vs Euphausiid conc.*	-.159	3	NS
Plankton volume vs Euphausiid conc.	.566	15	<.02

which includes column scattering strengths, fish and euphausiid concentrations, LEG density, and total plankton volume. The probabilities indicate the chance of (1) finding no correlation when one really exists or (2) obtaining a correlation when in fact none exists. In Table 6 correlations with probabilities greater than 0.05 were classed as insignificant: 32 percent of the relationships evaluated yielded significance probabilities of 0.05 or less. The correlation coefficient between night 12 kHz column strength and night plankton catch volume, -0.896, had the highest significant probability, namely less than 0.001.

The highly significant negative correlation between plankton volume and column strength was unexpected and seems contrary to previous work[9] which suggests that the intensity of open ocean volume reverberation is generally related to the organic productivity of a region and varies directly with the abundance (standing stock) of organisms in that region. This apparent anomaly is largely due to the influence of data from the Sea of Japan and the Sea of Okhotsk, where the overall plankton concentrations, mostly euphausiids, were

high and reverberation levels low. The influence of these data is indicated in Figure 22 which shows a regression line for reverberation and catch data from all stations, another for data from the Sea of Okhotsk and Japan Seas alone, and a third for data from the remaining regions. The figure clearly shows that data from the Sea of Japan and the Sea of Okhotsk were major factors in the establishment of a negative correlation between column strength and plankton volume. If plankton volumes and night 12 kHz column strengths from the Northwest Pacific, the South China Sea, and the East China Sea are compared as a group, there is a positive correlation, though not significant. This result further exemplifies the anomalous character of the data from the Japan and Okhotsk Seas.

A significant negative correlation was also found between column strength and euphausiid concentration. In addition, there is a positive correlation (probability level <0.02) between the mean nocturnal values for the geographical areas for plankton volume and euphausiid concentration, which indicates that euphausiids were the major component of the netted plankton. Euphausiids are thus implicated as major factors contributing to the negative correlation between column strength and plankton volume and, as expected, appear to have little effect on volume reverberation at the frequencies of interest for the cruise. This result is not surprising. Although authors[3,4] have suggested that euphausiids were the cause of 12 kHz scattering layers, subsequent studies have not substantiated the relationship.[30] Neither the spatial distributions[31,49] nor the acoustical characteristics[50,51] of euphausiids are adequate for the organisms to have a significant influence on scattering at frequencies as low as 12 kHz.

Although total plankton volume or standing crop within an area is not necessarily related to the level of reverberation there, certain specific portions of the zooplankton may be significant. As mentioned previously, the gas-filled bladders of fish and siphonophores[52] have been shown to be important mid-frequency sound scatterers. The FASOR II data show a significant positive correlation between total night fish concentration and day 3 KHz column strength. And though a significant correlation does not necessarily imply a casual relationship between the variables involved, these particular correlations, combined with other evidence presented previously, suggest that mesopelagic and other fish are important factors in volume reverberation, whereas total standing crop may be too general in index to be of value.

Correlations that involve catch data should be interpreted with caution, however, because of the biases and limitations inherent in both the biological sampling program and the sampler employed. The Tucker Trawl was designed to sample small mesopelagic fish and large zooplankton (i.e., euphausiids and shrimp the "primary plankton" of this report) and therefore its samples of larger fish, such as those resonant between 2 and 6 kHz or the likely causes of LEGs, are probably inadequate and its samples of small (i.e., "secondary") plankton are not rigorous. Thus, correlations that involve catch data, particularly secondary plankton data or biological comparisons with 3 kHz scattering strength or LEG observations, are only indicative of the complex biological/acoustical interactions encountered during FASOR II. Furthermore, because time on station was divided among a number of activities, the few hauls taken per station were insufficient to completely describe the scattering populations encountered. Moreover, daytime hauls often fished entirely above the DSL were typically devoid of mesopelagic fish that, in the layers, likely caused most of the scattering, particularly that measured at 12 kHz. Many fish, at depth in the DSL diurnally, migrated nearer the sea surface at dusk, however, and were captured in night

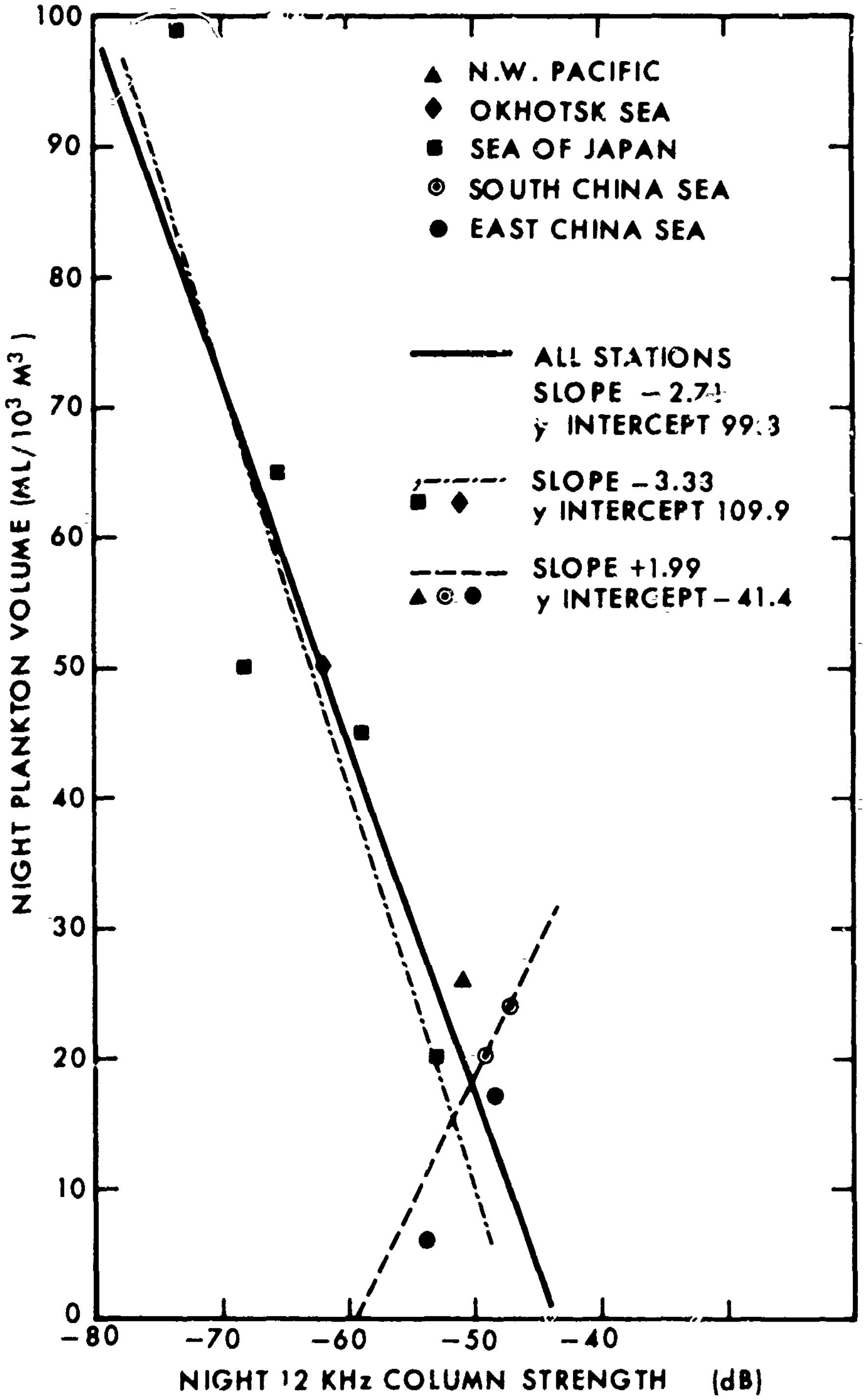


Figure 22 Scatter diagram of night plankton volume vs night 12 kHz column strength using area means. Least square regression lines are given to clarify areal relationships.

hauls. As a result, nocturnal catch data are applicable to both day and night acoustical measurements; interpretation of correlations that involve these data may have causal implications.

Figure 21 shows the relationship between station means of diurnal 12 kHz column strength and those of both nocturnal fish concentration and nocturnal LEG density. Again, the general concomitant decrease in fish concentrations and column strength values follows the basic model premise[40,41] that reverberation can be predicted from fish population densities, although more data must be tested to refine the predictive value of the model for specific applications. Conversely, LEGs had a negative correlation with column strength (see Fig. 21), their density decreased as volume reverberation increased. Echo groups, on average, tended to be rare where mesopelagic or other fish were taken in number. Although areas with high LEG concentrations generally had low scattering levels, spuriously high levels should be expected when echo groups are included in the water volume measured directly.

The values from comparisons reported in Table 6 should be considered only as indicators of overall trends and not as absolute indices of relationships. The variability of the data is large, particularly for comparisons that involve mean values from oceanographically-defined regions, and the significance of the resulting correlations may actually be less than is reported from the limited measurements made on this expedition. FASOR II was a long cruise, but only the spatial aspects of the acoustically-related conditions were evaluated. The seasonal changes in column strengths and the biological abundances, etc., within the individual regions during the cruise may have been at least as great as the changes noted for the values between the regions. However, because the investigations covered a wide geographical area and studies of seasonal variations of acoustical or biological conditions are, of necessity, regionally intensive, the data are insufficient for separation of the seasonal variations within the regions from the overall variability noted between the regions. To understand the nature of their variability, dynamic oceanic processes must be studied in both their temporal and spatial contexts.[53] The causal relationships underlying the trends of acoustical biological interactions of the sort reported here will become more evident as more information is available on the temporal aspects of acoustical[12] and biological[54,55] processes in the sea. An understanding of such casual relationships is the key to reliable predictive capability.

CONCLUSIONS

This report emphasizes the relationships between acoustical characteristics, physical oceanographic properties and certain forms of marine biota in the North Pacific Ocean. Physical properties delineated eight oceanic regions, each with defined water mass characteristics. The combination of biological/acoustical properties (echo groups and scattering layers observed, column scattering strengths measured and organisms captured) was distinctive enough to define a "signature" for each physically-defined area. Whether the difference in signatures was strictly the result of specific geographical locations or was partially seasonal in origin was indeterminable from this cruise. Table 7 summarizes the biological/acoustical characteristics by regions. The regional signatures are discussed below.

The concentration of Large Echo Groups (number per unit volume of insonified water) was very high in the Seas of Okhotsk and Japan, low in the Transitional and Central Subarctic Domains, the Western Pacific, and the East China Sea, and intermediate in other areas. Both LEG concentrations and their frequency of occurrence (the fraction of total hours in which LEGs were observed) were higher by day than at night in all areas except the Sea of Japan, where nocturnal values were significantly higher.

Scattering layers were typical on 12 kHz echo sounder records from all areas except the Sea of Japan, where layers occurred only near the Korean Straits. Complex patterns, generally with 3 or more layers, occurred in the Transitional Domain, the Northwest Pacific and the Sea of Okhotsk; simpler patterns occurred elsewhere.

Measured 3 and 12 kHz column strengths were mostly moderate (−50 to −65 dB). High day 12 kHz measurements were taken in the Central Subarctic Domain and the South China Sea. Twelve kHz column strength values were low in the Sea of Japan diurnally and in the sea of Okhotsk at night. Echo groups may have contributed significantly to volume scattering measured in the four areas of the Sea of Okhotsk, Sea of Japan, the East coast of Japan, and the South China Sea.

Large volumes of plankton, primarily Euphausiids, were netted in the Sea of Okhotsk and the Sea of Japan and off the East coast of Japan. Concentrations of mesopelagic fish exceeded $5/10^3 m^3$ in hauls from the Central Subarctic Domain and off the East coast of Japan; the Transitional Domain and the East China Sea had intermediate concentrations of such fish; other areas yielded less than 1 fish/$10^3 m^3$. Non-mesopelagic fish were caught in large numbers only in the East and South China Seas.

Overall, LEGs were generally observed near shore, but their distribution was not restricted to inshore areas. The echo groups tended to have patchy, highly variable distributions and their diel distribution with depth varied greatly from area to area. In the South China Sea, for example, the LEGs migrated daily with the scattering layers whereas in the Sea of Japan they showed no significant depth redistribution with time.

The concentration of echo groups and the intensity of 12 kHz scattering layers appear to be inversely related. A significant negative correlation was found between area values of 12 kHz column scattering strength (day and night) and night LEG concentrations. Echo groups abound where scattering layers were scarce as in the Japan and Okhotsk Seas, but they were infrequent where numerous layers were common as in the Northeast Pacific.

Table 7. Biological and Acoustic Summary by Oceanic Region

Oceanic Region	LLG's: Density: High (>0.1 LLG 10^6 m^3)	LLG's: Density: Medium (0.01–0.1 LLG 10^6 m^3)	LLG's: Density: Low (<0.01 LLG 10^6 m^3)	LLG's: Density: Significant Day/Night density difference (p < .05)	LLG's: Density: Day density Greater than night	LLG's: Density: Night density Greater than day	LLG's: Frequency of Occurrence: Day freq ≥ 100 larger than night frequency	LLG's: Frequency of Occurrence: Day freq < 100 larger than night frequency	Scattering layers: Occurrence: Number days observed ≥ 90	Scattering layers: Occurrence: Number days observed < 90	Scattering layers: Layer characteristics: Complex scattering (generally ≥ 2 layers)	Scattering layers: Layer characteristics: Simple scattering (generally ≤ 1 layers)	Most frequent layer depth: Day (fathoms): 0–75	Day (fathoms): 75–150	Day (fathoms): 150–225	Night (fathoms): 0–75	Night (fathoms): 75–150	Night (fathoms): 150–225	Acoustic Measurements: Integrated Column Strengths: High level (> −50 dB)	Acoustic Measurements: Medium level (−50 to −65 dB)	Acoustic Measurements: Low level (< −65 dB)	Acoustic Measurements: LFGs appear to be associated with volume scattering peaks	Biological Data: Total night displacement volumes: High (>50 ml 10^3 m^3)	Total night displacement volumes: Medium (20–49 ml 10^3 m^3)	Total night displacement volumes: Low (<19 ml 10^3 m^3)	Mesopelagic-night fish concentration: High (>5 10^3 m^3)	Mesopelagic-night fish concentration: Medium (1.0–4.9 10^3 m^3)	Mesopelagic-night fish concentration: Low (<1.0 10^3 m^3)	'Other' fish concentration: High (>1.0 10^3 m^3)	'Other' fish concentration: Medium (1–4.9 10^3 m^3)	'Other' fish concentration: Low (<1.0 10^3 m^3)
N. E. Pacific																															
Transitional Domain			X	X	X		X		X		X				X	X	X							X			X				X
Central Subarctic Domain			X	X	X		X		X			X			X			X	D					X		X					X
N. W. Pacific		X			•			X	X		X			X			X		n	DN				X				X			X
Sea of Okhotsk	X				•			X	X		X				+	+				dn	N	X	X					X			X
Western Pacific			X		•		X		X			X			+	+		+	NO				DATA								
East coast of Japan		X		X	X		X		X			X		X		X				Dd		X	X			X					X
Sea of Japan	X			X		X		X		X		X		X		X				N dn	D	X	X					X			X
East China Sea			X		•			X	X			X		X		X				D dn					X		X		X		
South China Sea		X		X	X		X		X			X	X			X			D	Nn	d	X			X			X	X		

+ less than 5 observations

* indicates observed characteristic for which there were too few observations to be statistically significant

Key
3 kHz 12 kHz
d D day
n N night

Thus, the concentration of midwater scatterers may be reduced in the presence of numerous LEGs, as indicated by the area distribution of mesopelagic fishes taken on FASOR II. In general, few such fish were captured on stations where LEGs were prominent.

The highly significant negative correlation between plankton volume and column strength, though unexpected, was mainly the result of high concentrations of plankton, mostly euphausiids, and low levels of scattering in the Sea of Japan and the Sea of Okhotsk.

Scattering intensities and layer configurations may remain consistent over relatively large oceanic regions because specific populations of swim bladder fishes and other organisms inhabit restricted domains with certain physical and chemical characteristics. In this study, both the plankton and fish populations were found to differ between water masses having distinctive biological/acoustical attributes. The importance of domain characteristics on these properties is further indicated by the positive correlation between total fish concentration (area means) and 12 kHz column scattering strength. Such water mass and biological/acoustical relationships are particularly important for the establishment and validation of predictive acoustic models.

REFERENCES

1. Chapman, R. P. 1967. Sound scattering in the Ocean, p. 161-183. *In* V. M. Albers (ed.) Underwater Acoustics. vol. 2. Plenum Press, New York 416 p.

2. Urick, R. J. 1967. Principles of underwater sound for engineers. McGraw-Hill, New York, 342 p.

3. Boden, B. P. 1950. Plankton organisms in the deep scattering layer. U. S. Navy Electronics Laboratory Rep. 186. 29 p.

4. Moore, H. B. 1950. The relation between the scattering layer and the Euphausiacea. Biol. Bull. 99:181-212.

5. Marshall, N. B. 1951. Bathypelagic fishes as sound scatterers in the ocean. J. Mar. Res. *10* (1):1-17.

6. Tucker, G. H. 1951. Relation of fishes and other organisms to the scattering of underwater sound. J. Mar. Res. *10* (2):215-238.

7. Hersey, J. B., and R. H. Backus. 1957. New evidence that migrating gas bubbles, probably the swimbladders of fish, are largely responsible for scattering layers on the continental rise of New England. Deep-Sea Res. *1* (3):190-191.

8. Barham, E. G. 1957. The ecology of sonic-scattering layers in the Monterey Bay area, California. Ph.D. Thesis. Hopkins Mar. Sta., Stanford Univ. Tech. Rept. No. 1, 182 p.

9. Batzler, W. E., and R. J. Vent. 1967. Volume-scattering measurements at 12 kc/sec in the Western Pacific. J. Acoust. Soc. Amer. *41* (1):154-157.

10. Pickwell, G. V., R. J. Vent, E. G. Barham, W. E. Batzler, and I. E. Davies. 1970. Biological acoustic scattering off Southern California, Baja California and Guadalupe Island, p. 490-507. *In* G. B. Farquhar (ed.) Proc. Int. Symp. Biol. Sound Scattering in the Ocean. Maury Center for Ocean Science, MC Rep. 005. U. S. Govt Printing Office, Washington, D. C. 629 p.

11. Adams, R. L., and R. R. Gardner. 1966. Computer processing of acoustic data at sea. J. Acoust. Soc. Amer. *39* (4):757-759.

12. Vent, R. J. 1972. Acoustic volume-scattering measurements at 3.5, 5.0 and 12.0 kHz in the eastern Pacific Ocean: Diurnal and seasonal variations. J. Acoust. Soc. Amer. *52* (1):373-382.

13. Davies, I. E., and E. G. Barham. 1969. The Tucker opening-closing micronekton net and its performance in a study of the deep scattering layer. Mar. Biol. *2* (2):127-131.

14. Suomala, J. B., Jr. 19[illegible]. Applying a digital computer simulation to evaluating echo sounder design and performance, p. 114-119. *In* Hilmar Kristjonsson (ed.) Modern fishing gear of the world, Vol. 3. Fishing News (Books) Ltd., London 516 p.

15. Dodimead, A. J., F. Favorite, and T. Hirano. 1962. Salmon of the North Pacific Ocean. Part II: Review of oceanography of the Subarctic Pacific Region. Bull. Int. North Pacific Fish Comm. 13. 195 p.

16. Sverdrup, H. U., M. W. Johnson, and R. H. Fleming. 1942. The Oceans, their physics, chemistry, and general biology. Prentice-Hall Inc., New York. 1087 p.

17. Andreeva, I. B., and Uy. G. Chindonova. 1964. On the nature of sound-scattering layers. Okeanologiya *4* (1):112-124 (in Russian).

18. Andreeva, I. B. 1972. The nature of scatterers and frequency characteristics of the sound scattering layers in the ocean. Akad. Nauk, SSSR, Okeanologiya *12* (6):982-986 (in Russian).

19. Hoffman, J. 1957. Hyperbolic curves applied to echo-sounding. Int. Hydrogr. Rev. *34*:45-55.

20. Parin, N. V. 1968. Ichthyofauna of the epipelagic zone. Akad. Nauk, SSSR, Institute of Oceanology (in Russian) *Translation* Israel Program for Scientific Translations Ltd., Jerusalem. 1970. 206 p.

21. Krause, D. C. 1971. Deep scattering layers resolved by narrow-beam echo sounder along 35°S in the South Pacific. New Zealand J. Mar. Freshwater Res. *5* (2):219-232.

22. Beklemishev, K. V. 1964. Echo-sounding records of macroplankton concentrations and their distribution in the Pacific Ocean. Trudy Inst. Okeanologii, Akad. Nauk, SSSR *65*:197-229 (in Russian) *Translation:* U. S. Naval Oceanographic Office Trans. 343, 1967. Washington, D. C.

23. Aron, W. 1962. The distribution of animals in the eastern north Pacific and its relationship to physical and chemical conditions. J. Fish. Res. Bd. Canada *19* (2):271-314.

24. Laurs, R. M. 1970. MS. Cruise Report. David Starr Jordan, Cruise No 56, October 5 October 22, 1970. U. S. Dept. Commerce, National Oceanic and Atmospheric Administration, National Marine Fisheries Service, Fishery-Oceanography Center, P. O. Box 271, La Jolla, Ca. 12 p.

25. McGowan, J. A. 1971. Oceanic biogeography of the Pacific, p. 3-74. *In* B. M. Funnell and W. R. Riedel (ed.) The Micropalaeontology of the oceans. Cambridge Univ. Press. 828 p.

26. Vannucci, M. 1968. Loss of organisms through the meshes, p. 77-86. *In* D. J. Tranter and J. H. Fraser (ed.) Zooplankton sampling. Monogr. on Oceanogr. Method. 2. UNESCO, Paris. 174 p.

27. Clutter, R. I., and M. Anraku. 1968. Avoidance of samplers, p. 57-76. *In* D. J. Tranter and J. H. Fraser (ed.) Zooplankton sampling. Monogr. on Oceanogr. Method. 2. UNESCO, Paris. 174 p.

28. Pearcy, W. B., and C. A. Forss. 1966. Depth distribution of oceanic shrimps (Decapoda: Natantia) off Oregon. J. Fish. Res. Bd. Canada *23* (8):1135-1143.

29. Brinton, E. 1962. The distribution of Pacific euphausiids. Bull. Scripps Inst. Oceanogr. 8(2):51-270.

30. Hersey, J. B., and R. H. Backus. 1962. Sound scattering by marine organisms. p. 498-539. *In* M. N. Hill (ed) The Sea, vol. 1. Wiley, New York. 864 p.

31. Barham, E. G. 1966. Deep scattering migration and composition: Observations from a diving saucer. Science *151*:1399-1403.

32. Farquhar, G. B. (ed.). 1970. Proc. Int. Symp. Biol. Sound Scattering in the Ocean. Maury Center for Ocean Science. MC Rep. 005. U. S. Govt Printing Office, Washington, D. C. 629 p.

33. Marshall, N. B. 1960. Swimbladder structure of deep-sea fishes in relation to their systematics and biology. Discovery Rep *31*:1-122.

34. Capen, R. L. 1967. Swimbladder morphology of some mesopelagic fishes in relation to sound scattering. U. S. Navy Electronics Lab. Rept. 1447. 31 p.

35. Andreeva, I. B. 1964. Scattering of sound by air bladders of fish in deep sound-scattering ocean layers. Ákust. Zh., *10*(1):20-24 (in Russian). *Translation:* Sov. Phys., Acoust. Am. Inst. Phys. 1964. *10*(1):17-20.

36. Weston, D. E. 1967. Sound propagation in the presence of bladder fish. p. 55-88. *In* V. M. Albers (ed.) Underwater acoustics II. Plenum Press, New York. 416 p. (Proc. 1966 NATO Adv. Stud. Inst., Copenhagen).

37. Chindonova, Yu. G., and N. I. Kashkin. 1969. Comparison of the biological and acoustic methods of assessing sound-scattering layers. Akad. Nauk, SSSR Okeanologiya 9(3):430-439.

38. Kashkin, N. I., and Yu. G. Chindonova. 1971. Mesopelagic fishes as resonance scatterers in the deep scattering layers of the Atlantic Ocean. Akad Nauk, SSSR. Okeanologiya *11*(3):482-493 (in Russian).

39. Batzler, W. E., W. A. Friedl, and J. W. Reese. 1972. Can acoustic volume scattering be predicted from net haul data? J. Acoust. Soc. Amer. *54*(1):290.

40. Batzler, W. E., J. W. Reese, and W. A. Friedl. 1975. Acoustic volume scattering: its dependence on frequency and biological scatterers. Naval Undersea Center TP 442. 25 p.

41. Batzler, W. E. 1972. A model for the prediction of acoustic volume scattering strength. Naval Undersea Center Tech. Note 859. 22 p.

42. Lindberg, G. U., and M. I. Legeza. 1965. Fishes of the Sea of Japan and the Adjacent areas of the Sea of Okhotsk and the Yellow Sea. Part 2. Keys to the fauna of the USSR. Zool. Inst., Akad. Nauk, SSSR, No. 84. (in Russian). *Translation* Israel Program for Scientific Translations, Jerusalem. 1969. 389 p.

43. Nafpaktitis, B. G., and M. Nafpaktitis. 1969. Lantern fishes (Family Myctophidae) collected during cruises 3 and 6 of the R/V Anton Bruun in the Indian Ocean. Bull. Los Angeles County Mus. Nat. Hist. Sci.: No. 5, 79 p.

44. Rass, T. S. (ed.) 1967. The fishes of the open waters of the Pacific Ocean. *In* V. G. Kort (ed.) The Pacific Ocean, Vol. 7, Part 3. Nauka, Moscow. p. 3-273 (in Russian). Translation: Naval Oceanographic Office. Transl. No. 528, 1971, 320 p.

45. Nafpaktitis, B. 1966. Two new fishes of the myctophid genus *Diaphus* from the Atlantic Ocean Bull. Mus. Comp. Zoo. Harvard Univ. *133* (9):401-424.

46. Kulikova, E. B. 1961. Data on the lantern fishes of the genus *Diaphus* (Family Scopelidae) from the western part of the Pacific Ocean. Trudy Inst. Okeanol. *43*:5-39 (in Russian). *Translation* Syst. Lab., Bur. Comm. Fish., U. S. Nat. Mus., Translation No. 61 42 p.

47. Batzler, W. E., and G V. Pickwell. 1970. Resonant acoustic scattering from gas-bladder fishes. p. 168-179. *In* G. B. Farquhar (ed.) Proc. Int. Symp. Biol. Sound Scattering in the Ocean. Maury Center for Ocean Science, MC rept. 005. U. S. Govt Printing Off., Washington, D. C. 629 p.

48. Simpson, G. G., A. Roe, and R. C. Lewontin. 1960. Quantitative zoology, revised edition. Harcourt, Brace and World, Inc., New York, 440 p.

49. Bary, B. M. 1966. Back scattering at 12 kc/s in relation to biomass and numbers of zooplanktonic organisms in Saanich Inlet, British Columbia. Deep-Sea Res. *13* (4):655-666.

50. Beamish, P. 1971. Quantitative measurements of acoustic scattering from zooplanktonic organisms. Deep-Sea Res. *18* (8):811-822.

51. Cooney, R. T. 1971. Zooplankton and micronekton associated with a diffusive sound-scattering layer in Puget Sound, Washington. Ph.D. Thesis. Univ. Washington. 208 p.

52. Barham E. G. 1963. Siphonophores and the deep scattering layer. Science *140*:826-828.

53. Gordon, D. C., Jr. 1971. Distribution of particulate organic carbon and nitrogen at an oceanic station in the central Pacific. Deep-Sea Res. *18* (11):1127-1134.

54. Gibbs, R. H., Jr., and C. F. E. Roper. 1970. Ocean Acre: preliminary report on vertical distribution of fishes and cephalopods, p. 119-133. *In* G. B. Farquhar (ed.) Proc. Int. Symp. Biol. Sound Scattering in the Ocean. Maury Center for Ocean Science, MC Rep. 005. U.S. Govt Printing Office., Washington, D. C. 629 p.

55. Clarke, T. A. 1973. Some aspects of the ecology of lantern fishes (MYCTOPHIDAE) in the Pacific Ocean near Hawaii. Fish. Bull. *71* (2):401-433.

BIBLIOGRAPHY

Adams, R. L., and R. R. Gardner. 1966. Computer processing of acoustic data at sea. J. Acoust. Soc. Amer. *39* (4):757-759.

Andreeva, I. B. 1964. Scattering of sound by air bladders of fish in deep sound-scattering ocean layers. Akust. Zh., *10* (1):20-24 (in Russian). *Translation*: Sov. Phys., Acoust. Am. Inst. Phys. 1964. *10* (1): 17-20.

Andreeva, I. B. 1972. The nature of scatterers and frequency characteristics of the sound scattering layers in the ocean. Akad. Nauk, SSSR, Okeanologiya *12* (6):982-986 (in Russian).

Andreeva, I. B., and Yu. G. Chindonova. 1964. On the nature of sound-scattering layers. Akad. Nauk, SSSR, Okeanologiya *4* (1):112-124 (in Russian).

Aron, W. 1962. The distribution of animals in the eastern north Pacific and its relationship to physical and chemical conditions. J. Fish. Res. Bd. Canada *19* (2):271-314.

Barham, E. G. 1957. The ecology of sonic-scattering layers in the Monterey Bay area, California. Ph.D. Thesis. Hopkins Mar. Sta., Stanford Univ. Tech. Rept. No. 1, 182 p.

Barham, E. G. 1963. Siphonophores and the deep scattering layer. Science *140*:826-828.

Barham, E. G. 1966. Deep scattering migration and composition: Observations from a diving saucer. Science *151*:1399-1403.

Bary, B. M. 1966. Back scattering at 12 kc/s in relation to biomass and numbers of zooplanktonic organisms in Saanich Inlet, British Columbia. Deep-Sea Res. *13* (4):655-666.

Batzler, W. E. 1972. A model for the prediction of acoustic volume scattering strength. Naval Undersea Center Tech. Note 859. 22 p.

Batzler, W. E., W. A. Friedl, and J. W. Reese. 1973. Can acoustic volume scattering be predicted from net haul data? J. Acoust. Soc. Amer. *54* (1):290.

Batzler, W. E., and G. V. Pickwell. 1970. Resonant acoustic scattering from gas-bladder fishes, p. 168-179. *In* G. B. Farquhar (ed.) Proc. Int. Symp. Biol. Sound Scattering in the Ocean. Maury Center for Ocean Science, MC rept. 005. U. S. Govt Printing Off., Washington, D. C. 629 p.

Batzler, W. E., J. W. Reese and W. A. Friedl. 1975. Acoustic volume scattering: its dependence on frequency and biological scatterers. Naval Undersea Center TP 442. 25 p.

Batzler, W. E., and R. J. Vent. 1967. Volume-scattering measurements at 12 kc/sec in the Western Pacific. J. Acoust. Soc. Amer. *41* (1):154-157.

Beamish, P. 1971. Quantitative measurements of acoustic scattering from zooplanktonic organisms. Deep-Sea Res. *18* (8):811-822.

Beklemishev, K. V. 1964. Echo-sounding records of macroplankton concentrations and their distribution in the Pacific Ocean. Trudy Inst. Okeanologii, Akad. Nauk, SSSR *65*: 197-229 (in Russian) *Translation* U. S. Naval Oceanographic Office Trans. 343, 1967. Washington, D. C.

Boden, B. P. 1950. Plankton organisms in the deep scattering layer. U. S. Navy Electronics Laboratory Rep. 186. 29 p.

Brinton, E. 1962. The distribution of Pacific euphausiids. Bull. Scripps Inst. Oceanogr. *8* (2):51-270.

Capen, R. L. 1967. Swimbladder morphology of some mesopelagic fishes in relation to sound scattering. U. S. Navy Electronics Lab. Rept. 1447. 31 p.

Chapman, R. P. 1967. Sound scattering in the Ocean, p. 161-183. *In* V. M. Albers (ed.) Underwater Acoustics, vol. 2. Plenum Press, New York 416 p.

Chindonova, Yu. G., and N. I. Kashkin. 1969. Comparison of the biological and acoustic methods of assessing sound-scattering layers. Akad. Nauk, SSSR, Okeanologiya 9 (3): 430-439.

Clarke, T. A. 1973. Some aspects of the ecology of lantern fishes (MYCTOPHIDAE) in the Pacific Ocean near Hawaii. Fish. Bull. *71* (2): 401-433.

Clutter, R. I., and M. Anraku. 1968. Avoidance of samplers, p. 57-76. *In* D. J. Tranter and J. H. Fraser (ed.) Zooplankton sampling. Monogr. on Oceanogr. Method. 2. UNESCO, Paris. 174 p.

Cooney, R. T. 1971. Zooplankton and micronekton associated with a diffusive sound-scattering layer in Puget Sound, Washington. Ph.D. Thesis. Univ. Washington. 208 p.

Davies, I. E., and E. G. Barham. 1969. The Tucker opening-closing micronekton net and its performance in a study of the deep scattering layer. Mar. Biol. 2 (2):127-131.

Dodimead, A. J., F. Favorite, and T. Hirano. 1962. Salmon of the North Pacific Ocean. Part II: Review of oceanography of the Subarctic Pacific Region. Bull. Int. North Pacific Fish Comm. 13. 195 p.

Farquhar, G. B. (ed.). 1970. Proc. Int. Symp. Biol. Sound Scattering in the Ocean. Maury Center for Ocean Science. MC Rep. 005. U. S. Govt Printing Office, Washington, D.C. 629 p.

Gibbs, R. H., Jr., and C. F. E. Roper. 1970. Ocean Acre: preliminary report on vertical distribution of fishes and cephalopods, p. 119-133. *In* G. B. Farquhar (ed.) Proc. Int. Symp. Biol. Sound Scattering in the Ocean. Maury Center for Ocean Science, MC Rep. 005. U. S. Govt Printing Office, Washington, D. C 629 p.

Gordon, D. C., Jr. 1971. Distribution of particulate organic carbon and nitrogen at an oceanic station in the central Pacific. Deep-Sea Res. *18* (11):1127-1134.

Hersey, J. B., and R. H. Backus. 1957. New evidence that migrating gas bubbles, probably the swimbladders of fish, are largely responsible for scattering layers on the continental rise of New England. Deep-Sea Res. *1* (3):190-191.

Hersey, J. B., and R. H. Backus. 1962. Sound scattering by marine organisms, p. 498-539. *In* M. N. Hill (ed.) The Sea, vol. 1. Wiley, New York. 864 p.

Hoffman, J. 1957. Hyperbolic curves applied to echo-sounding. Int. Hydrogr. Rev. *34*:45-55.

Kashkin, N. I., and Yu. G. Chindonova. 1971. Mesopelagic fishes as resonance scatterers in the deep scattering layers of the Atlantic Ocean. Akad. Nauk. SSSR, Okeanologiya *11* (3):482-493 (in Russian).

Krause, D. C. 1971. Deep scattering layers resolved by narrow-beam echo sounder along 35°S in the South Pacific. New Zealand J. Mar. Freshwater Res. *5* (2):219-232.

Kulikova, E. B. 1961. Data on the latern fishes of the genus *Diaphus* (Family Scopelidae) from the western part of the Pacific Ocean. Trudy Inst. Okeanol. *43*:5-39 (in Russian). *Translation*: Syst. Lab., Bur. Comm. Fish., U. S. Nat. Mus., Translation No. 61. 42 p.

Laurs, R. M. 1970. MS. Cruise Report. David Starr Jordan, Cruise No. 56, October 5 – October 22, 1970. U. S. Dept. Commerce, National Oceanic and Atmospheric Administration, National Marine Fisheries Service, Fishery-Oceanography Center, P. O. Box 271, La Jolla, Ca. 12 p.

Lindberg, G. U., and M. I. Legeza. 1965. Fishes of the Sea of Japan and the adjacent areas of the Sea of Okhotsk and the Yellow Sea, Part 2. Keys to the fauna of the USSR, Zool. Inst., Akad. Nauk, SSSR, No. 84. (in Russian). *Translation*: Israel Program for Scientific Translations, Jerusalem. 1969. 389 p.

Marshall, N. B. 1951. Bathypelagic fishes as sound scatterers in the ocean. J. Mar. Res. *10* (1):1-17.

Marshall, N. B. 1960. Swimbladder structure of deep-sea fishes in relation to their systematics and biology. Discovery Rep. *31*:1-122.

McGowan, J. A. 1971. Oceanic biogeography of the Pacific, p. 3-74. *In* B. M. Funnell and W. R. Riedel (ed.) The Micropalaeontology of the oceans. Cambridge Univ. Press. 828 p.

Moore, H. B. 1950. The relation between the scattering layer and the Euphausiacea. Biol. Bull. *99*:181-212.

Nafpaktitis, B. 1966. Two new fishes of the myctophid genus *Diaphus* from the Atlantic Ocean Bull. Mus. Comp. Zool. Harvard Univ. *133* (9):401-424.

Nafpaktitis, B. G., and M. Nafpaktitis. 1969. Lantern fishes (Family Myctophidae) collected during cruises 3 and 6 of the R/V Anton Bruun in the Indian Ocean. Bull. Los Angeles County Mus. Nat. Hist. Sci.: No. 5, 79p.

Parin, N. V. 1968. Ichthyofauna of the epipelagic zone. Akad. Nauk. SSSR. Institute of Oceanology (in Russian) *Translation.* Israel Program for Scientific Translations Ltd., Jerusalem. 1970. 206 p.

Pearcy, W. G., and C. A. Forss. 1966. Depth distribution of oceanic shrimps (Decapoda; Natantia) off Oregon. J. Fish. Res. Bd. Canada *23* (8): 1135-1143.

Pickwell, G. V., R. J. Vent, E. G. Barham, W. E. Batzler, and I. E. Davies. 1970. Biological acoustic scattering off Southern California, Baja California and Guadalupe Island, p. 490-507. *In* G. B. Farquhar (ed.) Proc. Int. Symp. Biol. Sound Scattering in the Ocean. Maury Center for Ocean Science, MC Rep. 005. U. S. Govt Printing Office, Washington, D. C. 629 p.

Rass, T. S. (ed.) 1967. The fishes of the open waters of the Pacific Ocean. *In* V. G. Kort (ed.) The Pacific Ocean, Vol. 7, Part 3. Nauka, Moscow. p. 3-273 (in Russian). Translation. Naval Oceanographic Office. Transl. No. 528, 1971, 320 p.

Simpson, G. G., A. Roe, and R. C. Lewontin. 1960. Quantitative zoology, revised edition. Harcourt, Brace and World, Inc., New York, 440 p.

Suomala, J. B., Jr. 1971. Applying a digital computer simulation to evaluating echo sounder design and performance, p. 114-119. *In* Hilmar Kristjonsson (ed.) Modern fishing gear of the world, Vol. 3. Fishing News (Books) Ltd., London 516 p.

Sverdrup, H. U., M. W. Johnson, and R. H. Fleming. 1942. The Oceans, their physics, chemistry, and general biology. Prentice-Hall Inc., New York. 1087 p.

Tucker, G. H. 1951. Relation of fishes and other organisms to the scattering of underwater sound. J. Mar. Res. *10* (2): 215-238.

Urick, R. J. 1967. Principles of underwater sound for engineers. McGraw-Hill, New York. 342 p.

Vannucci, M. 1968. Loss of organisms through the meshes, p. 77-86. *In* D. J. Tranter and J. H. Fraser (ed.) Zooplankton sampling. Monogr. on Oceanogr. Method. 2. UNESCO, Paris. 174 p.

Vent, R. J. 1972. Acoustic volume-scattering measurements at 3.5, 5.0 and 12.0 kHz in the eastern Pacific Ocean: Diurnal and seasonal variations. J. Acoust. Soc. Amer. *52* (1): 373-382.

Weston, D. E. 1967. Sound propagation in the presence of bladder fish, p. 55-88. *In* V. M. Albers (ed.) Underwater acoustics II. Plenum Press, New York. 416 p. (Proc. 1966 NATO Adv. Stud. Inst., Copenhagen).

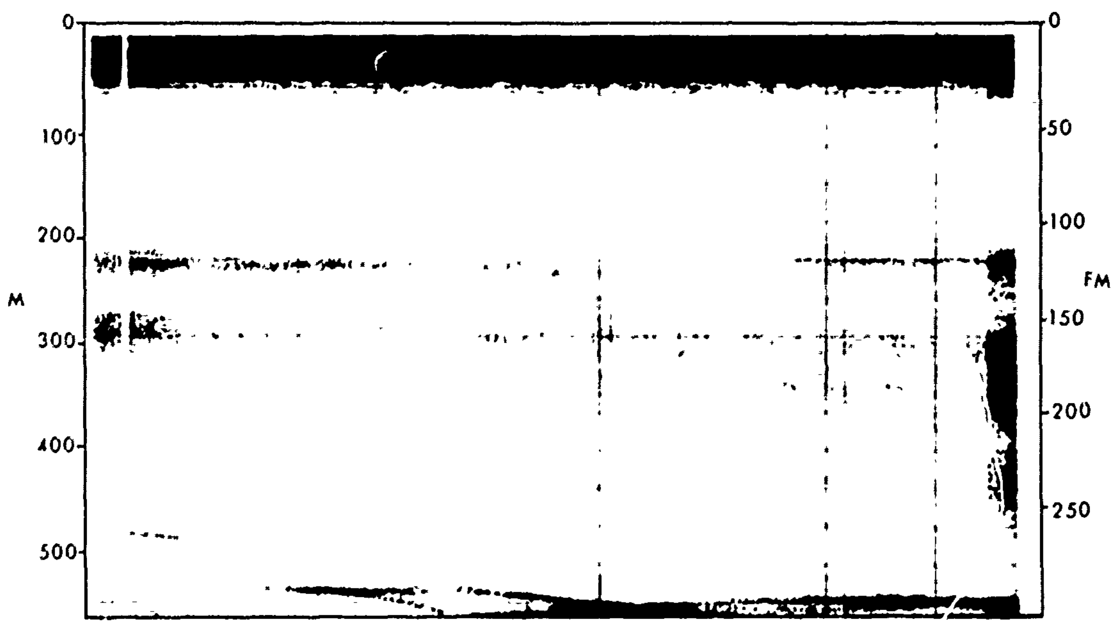
APPENDIX A – SECTIONS OF DAY AND NIGHT 12 KHZ ECHOGRAMS DEPICTING LEG AND SCATTERING LAYER CONFIGURATIONS

This appendix presents photographs and descriptive data of echograms recorded for day and night scattering during FASOR II operation. Following is each figure number identified with its pertinent recording data. (Recorder moves from left to right, with earlier times noted on the right. Bottom, if depicted, is generally cycled below the depth of the layers.)

1A. Morning (downward) migration
2A. Day scattering layers.
3A. Night scattering layers.
4A. Night scattering layer.
5A. Day scattering.
6A. Evening migration and night layering.
7A. Day Scattering.
8A. Night scattering.
9A. Day scattering.
10A. Night scattering.
11A. Day scattering.
12A. Night scattering.
13A. Day scattering.
14A. Day scattering.
15A. Day scattering.
16A. Day scattering.
17A. Day scattering.
18A. Night scattering.
19A. Day scattering.
20A. Night scattering.
21A. Night scattering.
22A. Day scattering.
23-25A. Recorder scale comparison.
26A. Night scattering.
27A. Day scattering.
28A. Night scattering.
29A. Scale and signal length comparisons.
30A. Day scattering.
31A. Night scattering.
32A. Day scattering.
33A. Day scattering.
34A. Day scattering.
35A. Day scattering.
36A. Day scattering.
37A. Day scattering.
38A. Day scattering.
39A. Night scattering.
40A. Night scattering.
41A. Day scattering.

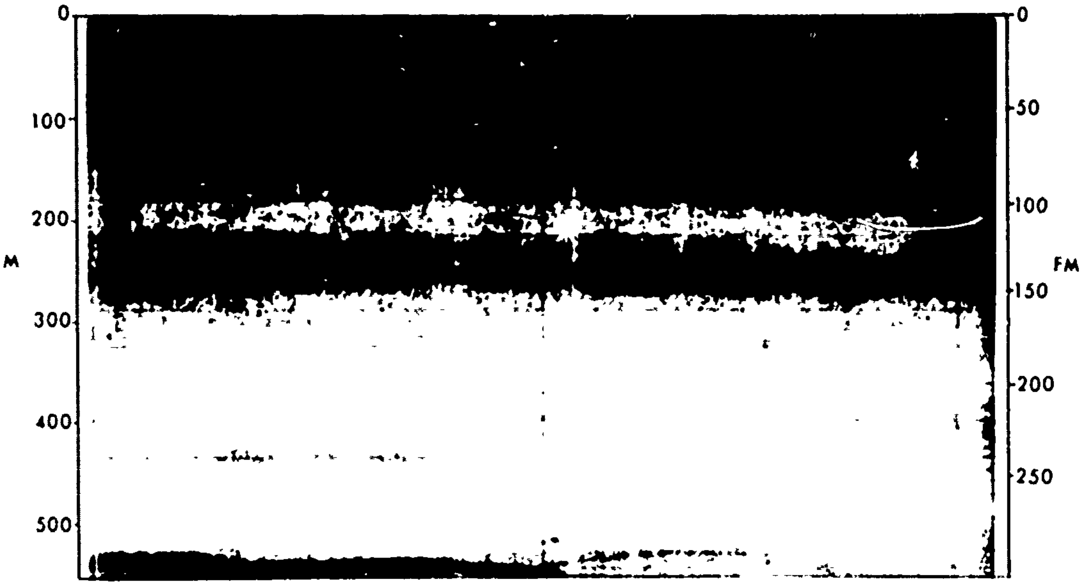
Area. Enroute Station A. (Transitional Domain)
Time 0530-0806, 8 Feb
Note Downward migration, starting at 0545, displays a number of crossovers. Overall pattern complex.

1A. Morning (downward) migration



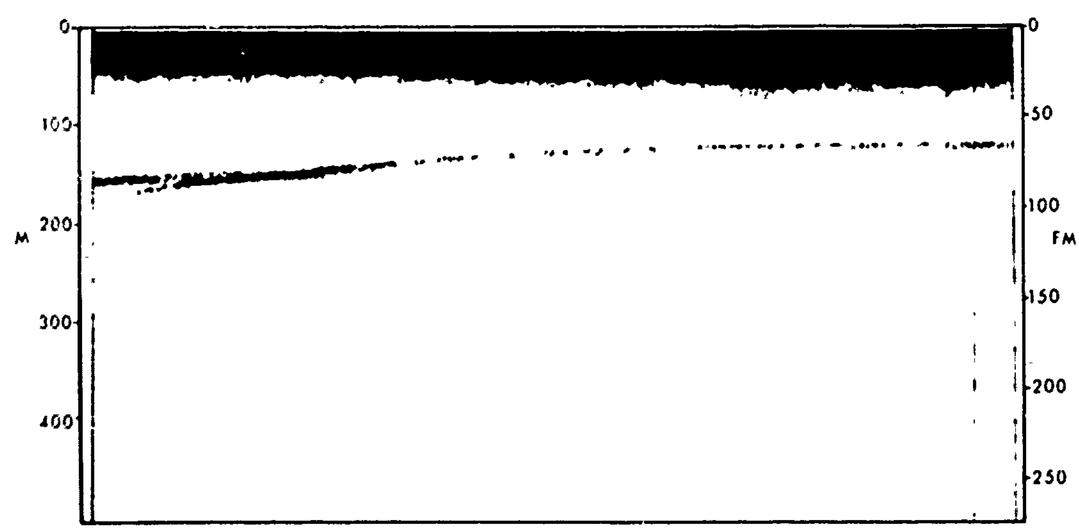
Area: Station A
Time. 1335-1430, 9 Feb.
Note Two major layers between 200 and 360 m, with a possible deep layer at 450 m

2A. Day scattering layers.



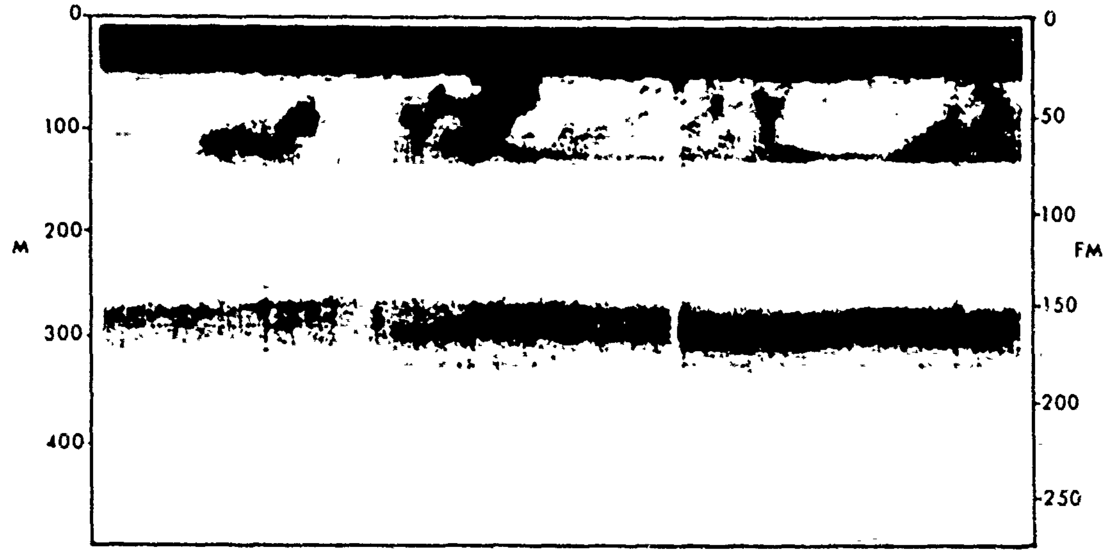
Area: Station A
Time 1810-1905, 9 Feb.
Note Extremely heavy surface layering with scattering to 450 m.

3A. Night scattering layers.



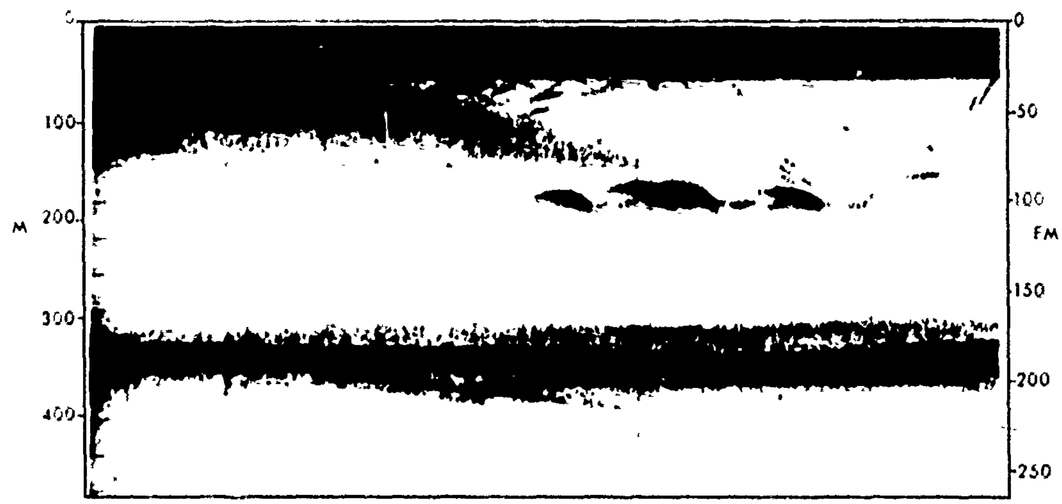
Area: Station B. (Central Subarctic Domain)
Time: 1900-1955, 13 Feb.
Note: Single diffuse layer at 350 m.

4A. Night scattering layer.



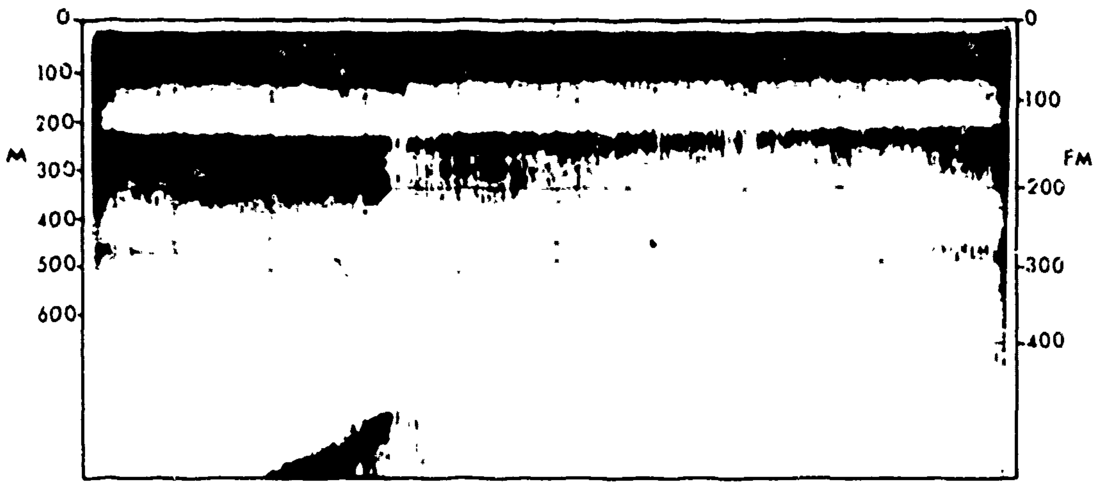
Area Station C (Central Subarctic Domain)
Time 0545 0640, 19 Feb
Note Near surface cloud-like scattering to 125 m. Heavy DSL at 300 m.
Apparent MEGs from surface to 100 m

5A. Day scattering.



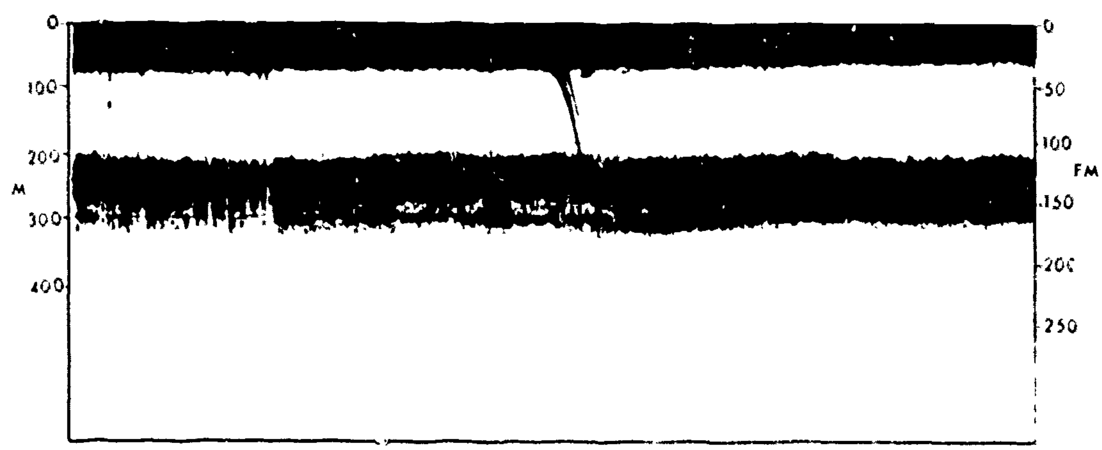
Area Station C
Time 1810-1905, 20 Feb.
Note LEG-like traces at 175 m are bubble trains from explosive devices
used in broadband acoustic measurements Deep non-migratory
layer at 340 m.

6A. Evening migration and night layering.



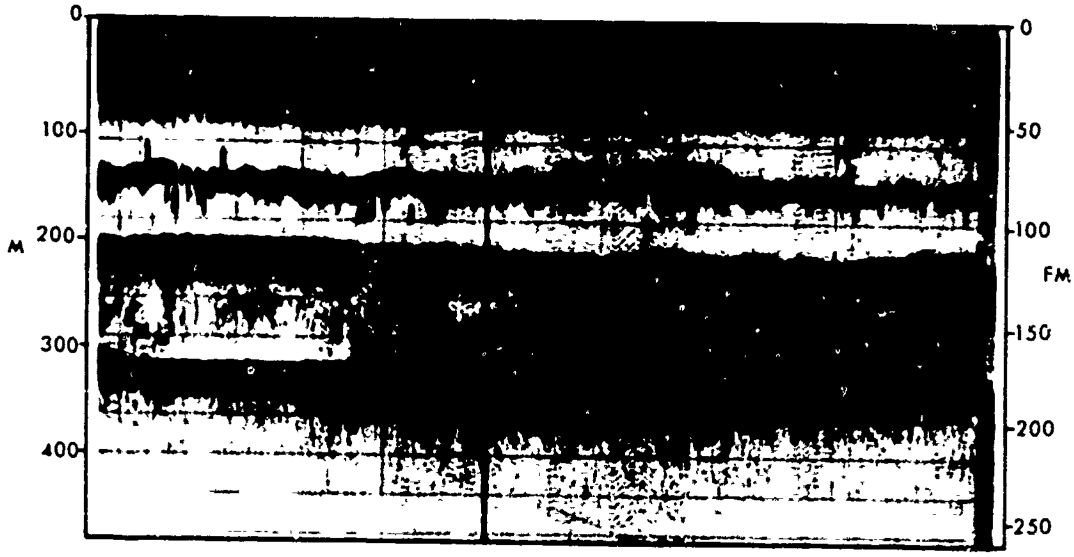
Area. Station D (Western Subarctic Domain)
Time 0840-1100, 1 Mar
Note Dense layer from 220-300 m and deeper layer at 450 m.

7A. Day Scattering.



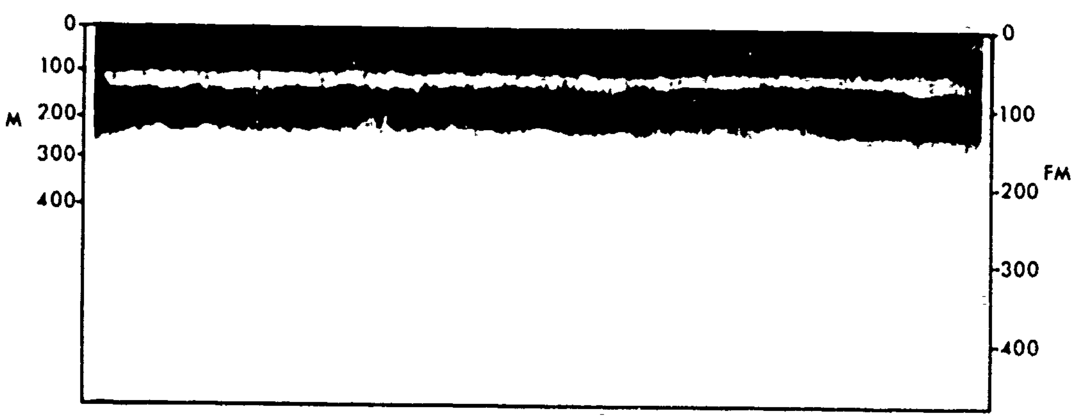
Area Station D. (Western Subarctic Domain)
Time 0425 0548, 2 Mar.
Note Single dense layer between 200 and 300 m.

8A. Night scattering.



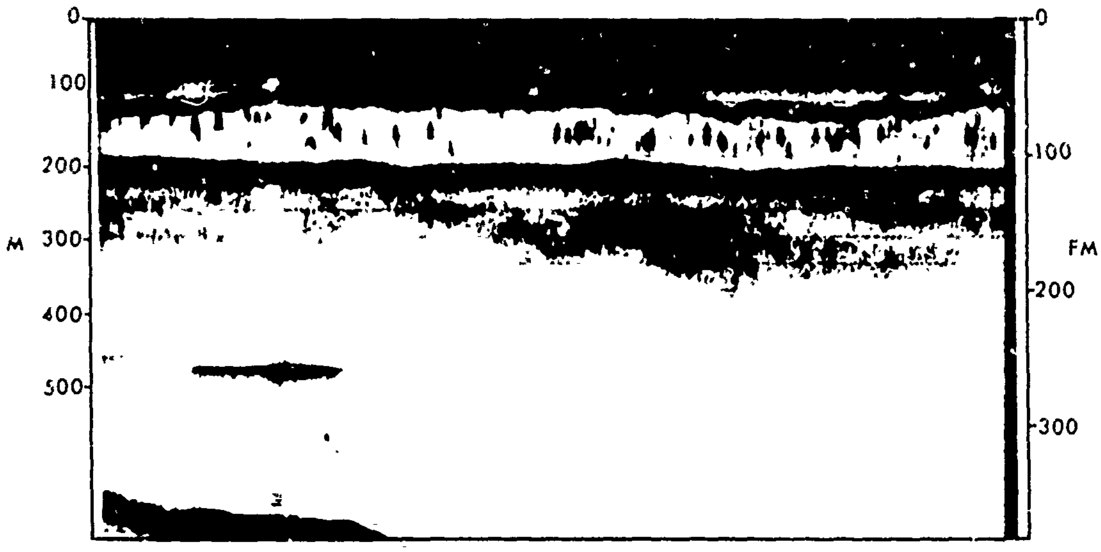
Area. Enroute Station E
Time. 1020-1118, 4 Mar.
Note Both scattering layer and small LEGs associated with the thermocline at 130 m Heavy layer at 200 to 230 m.

9A. Day scattering.



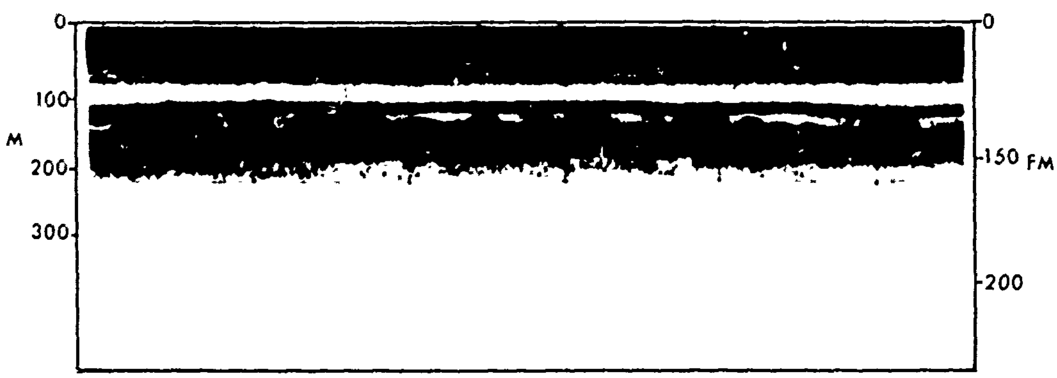
Area. Station E (Western Subarctic Domain)
Time 0010-0230, 4 Mar.
Note Heavy scattering 130 to 200. Detail lost due to scale compression.

10A. Night scattering.



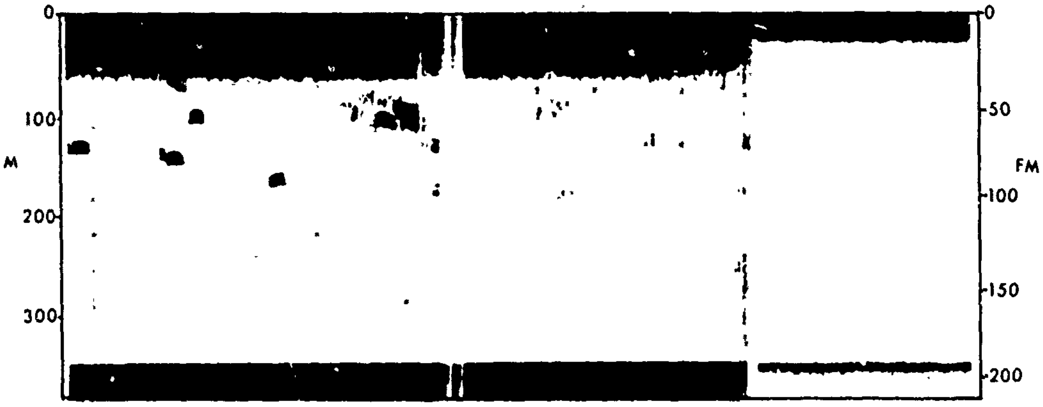
Area	Enroute Station F
Time	1430-1530, 5 Mar
Note	Depth of thermocline is associated with dense scattering layer at 120 m. LEGs confined to a narrow band between 120 and 200 m. A dense scattering layer appears at 200 m with diffuse scattering below that to 350 m

11A. Day scattering.



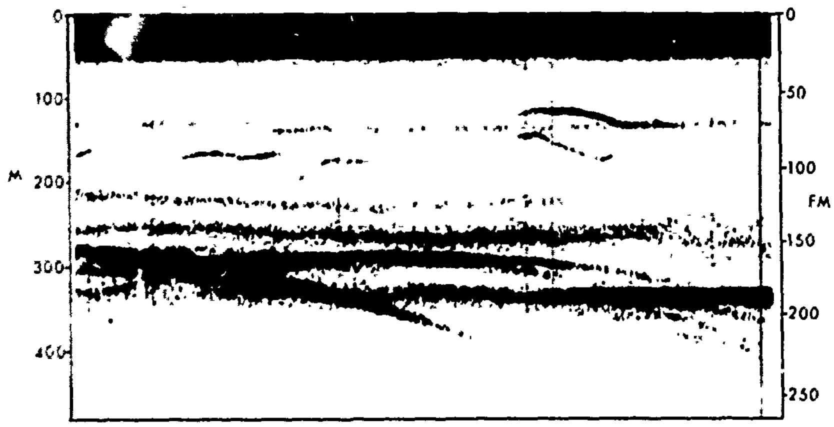
Area	Station F. (Western Subarctic Domain)
Time	2325-0045, 5-6 Mar
Note	LEGs and scattering organisms apparently compressed against the thermocline at 110 m. Migration appears to be limited by the extremely cold surface water.

12A. Night scattering.



Area Station G
Time 1040-1135, 10 Mar.
Note: Discrete targets show elongation and striation and remain in the sound cone as long as 20 min. Thermocline may again be represented at 120 m (Ship stopped).

13A. Day scattering.

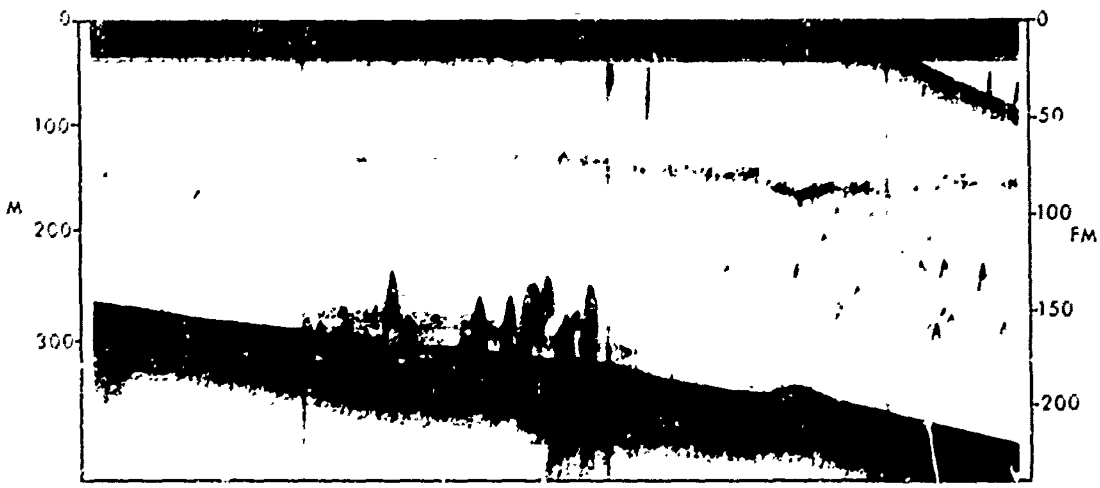


Area: Station H. (Okhotsk Sea
Time 1640-1740, 13 Mar.
Note A number of discrete echo groups are visible to 300 m. Very little other scattering.

14A. Day scattering.

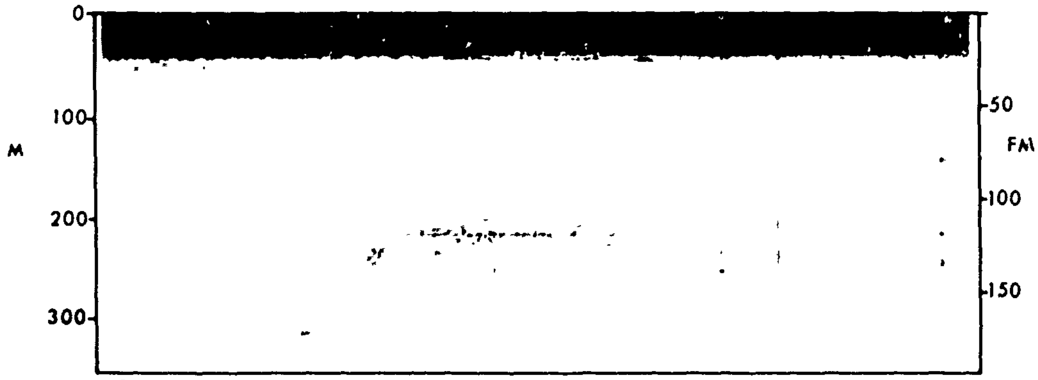
Area	Enroute Yokosuka. (Western Pacific)
Time	1420-1515, 18 Mar
Note	Combination of both echo groups and diffuse scattering. Heavy trace on the right side of the gram is due to an increase in signal length. The apparent layer of small LEGs was a common occurrance for the Western Pacific and the East Coast of Japan

15A. Day scattering.



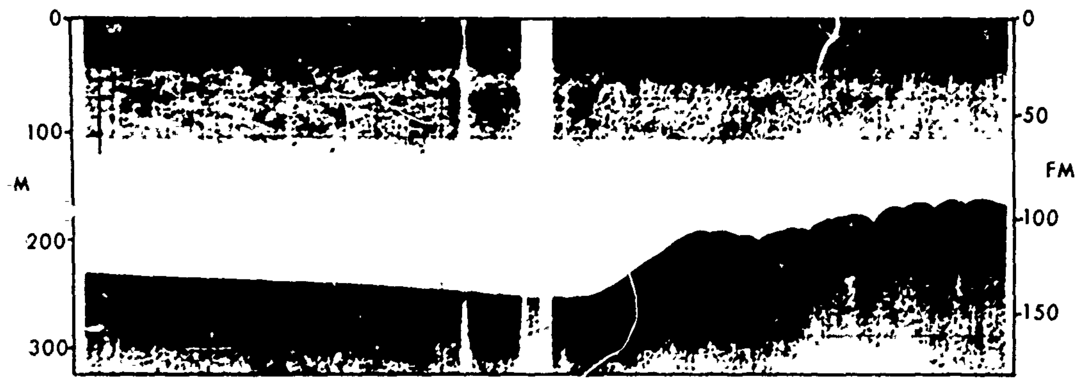
Area	Enroute Station I
Time	0855-0950, 4 Apr
Note	Shallow water area off the East Coast of Japan displaying both LEGs and scattering near the bottom at 300 m

16A. Day scattering



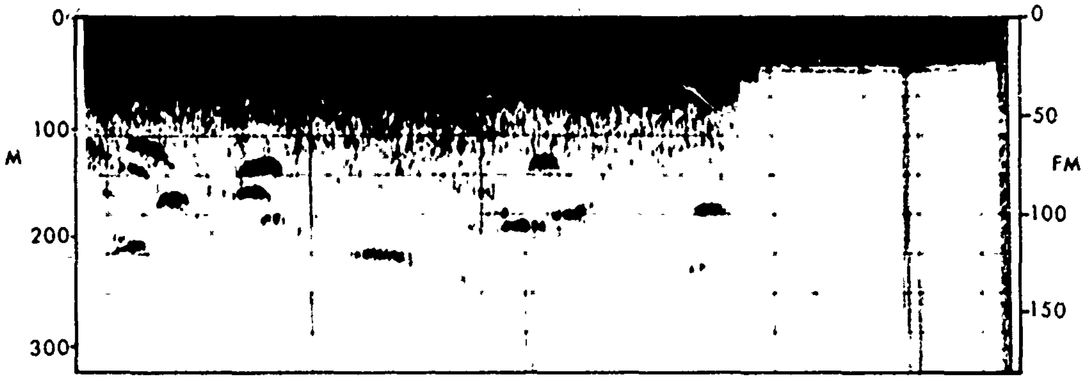
Area: Station I. (East coast of Japan)
Time. 1300-1355, 6 Apr.
Note. Three diffuse layers are discernable between 150 and 375 m.

17A. Day scattering.



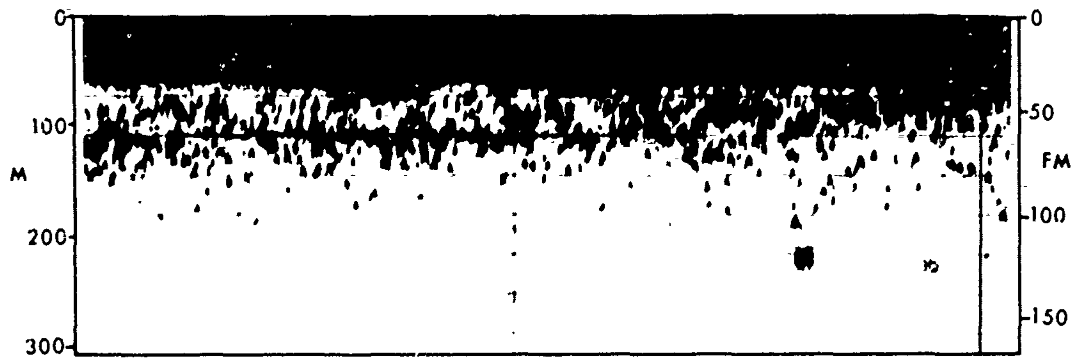
Area: Station I
Time: 2220-2315, 6 Apr.
Note: Heavy surface scattering to 100 m. Possible MEGs within scattering.

18A. Night scattering.



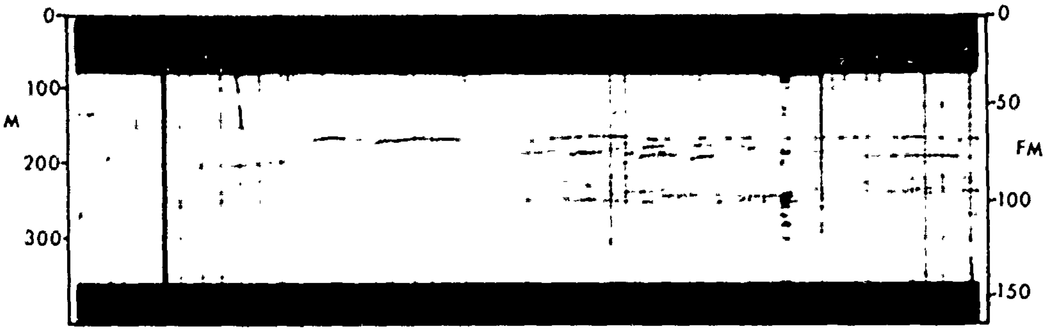
Area: Station J. (Sea of Japan)
Time. 0900-1000, 10 Apr.
Note: Scattered LEGs to 220 m. Apparent diffuse scattering appears to be an artifact of high signal length and gain.

19A. Day scattering.



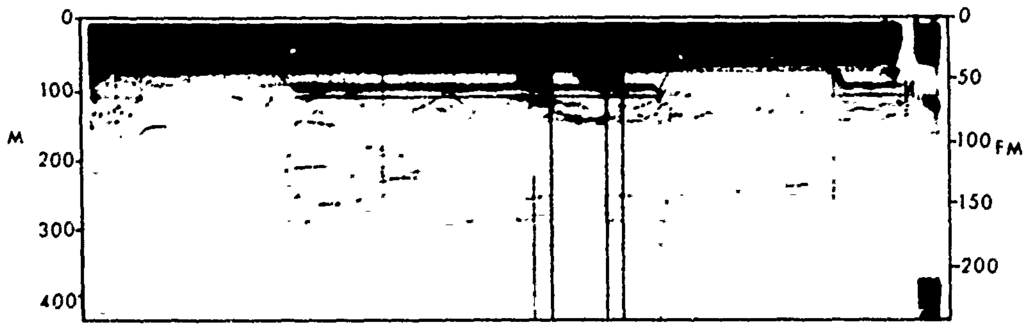
Area: Enroute Station K
Time 0130-0225, 11 Apr.
Note. Very large numbers of small LEGs from near surface to 175 m. No visible diffuse scattering.

20A. Night scattering.



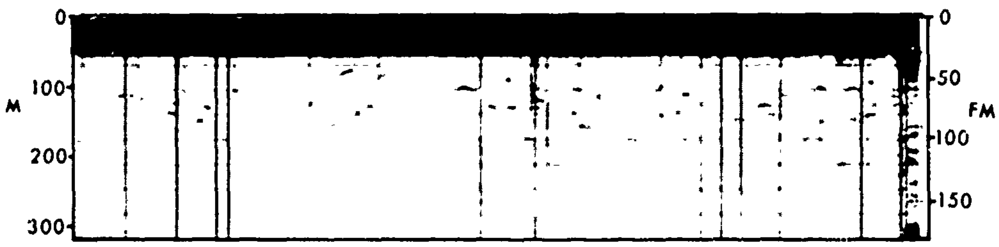
Area	Station L
Time	2030-2125, 14 Apr
Note	Large numbers of elongated echo groups to 300 m Up to 18 echo groups in sound cone simultaneously for up to 20 min No detectable scattering layers.

21A. Night scattering.



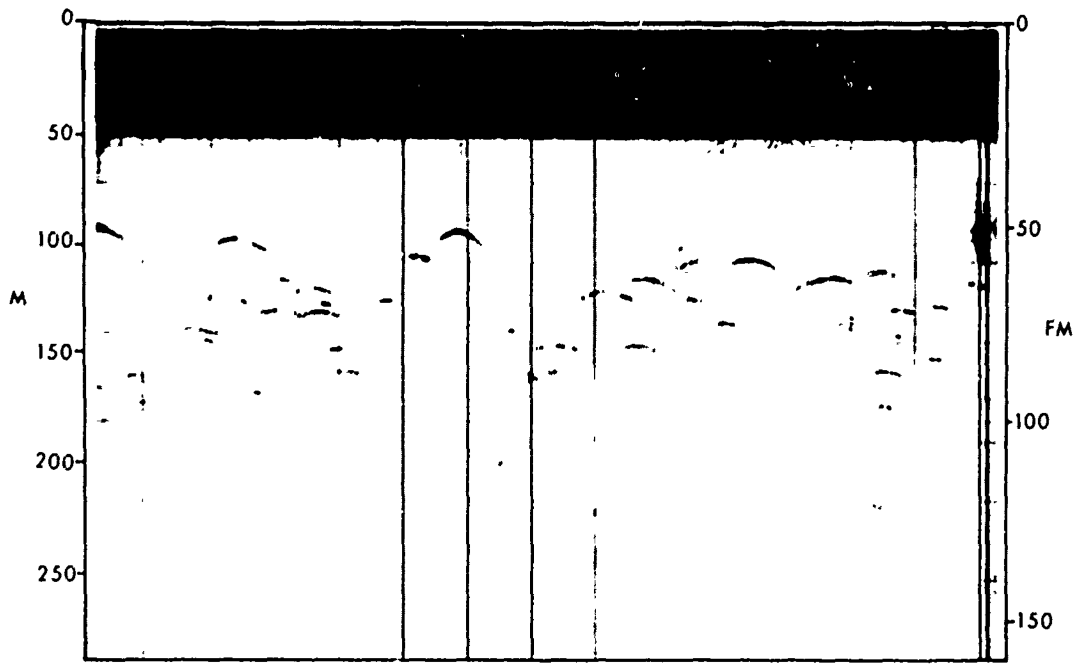
Area	Station L
Time	1110-1235, 15 Apr
Note	Individual echo groups observed to 300 m. Zig zag pattern near 100 m may be fish response to explosive devices represented by the dark traces near the surface

22A. Day scattering.



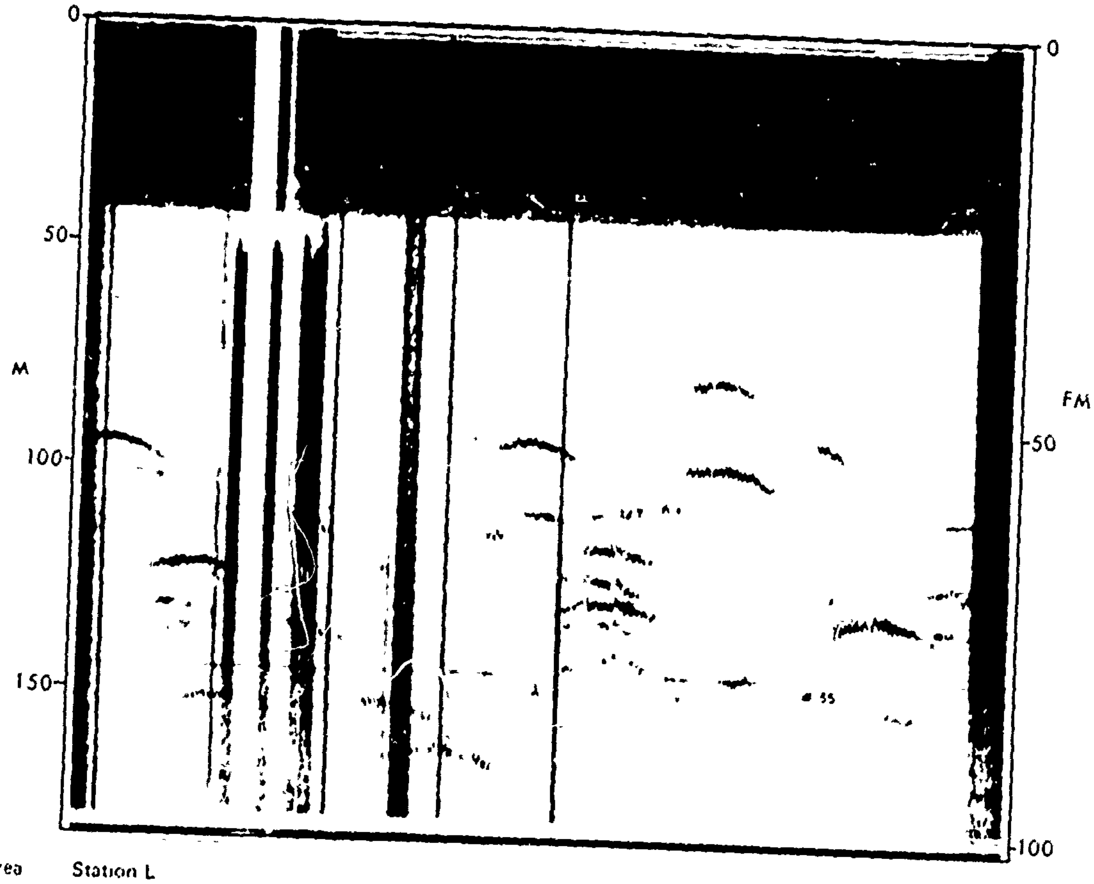
Area: Station L
Time: 0030-0255
Note The echo grams show the amplifying effect of scale changes. 600 Fm. scale. Echo groups are small, individual signals are not visible.

Figure 23A. Recorder scale comparison.



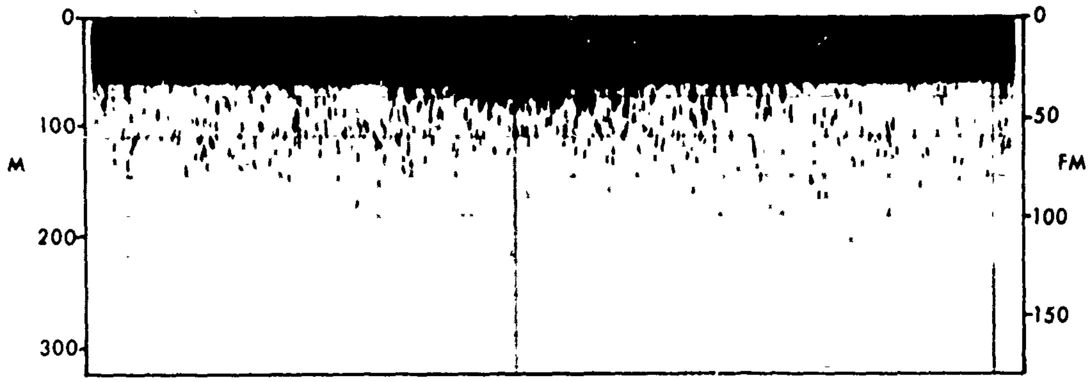
Area: Station L
Time 0030-0225
Note The echo grams show the amplifying effect of scale changes. 200 Fm. scale. Echo groups larger, individual signals are distinguishable.

Figure 24A. Recorder scale comparison.



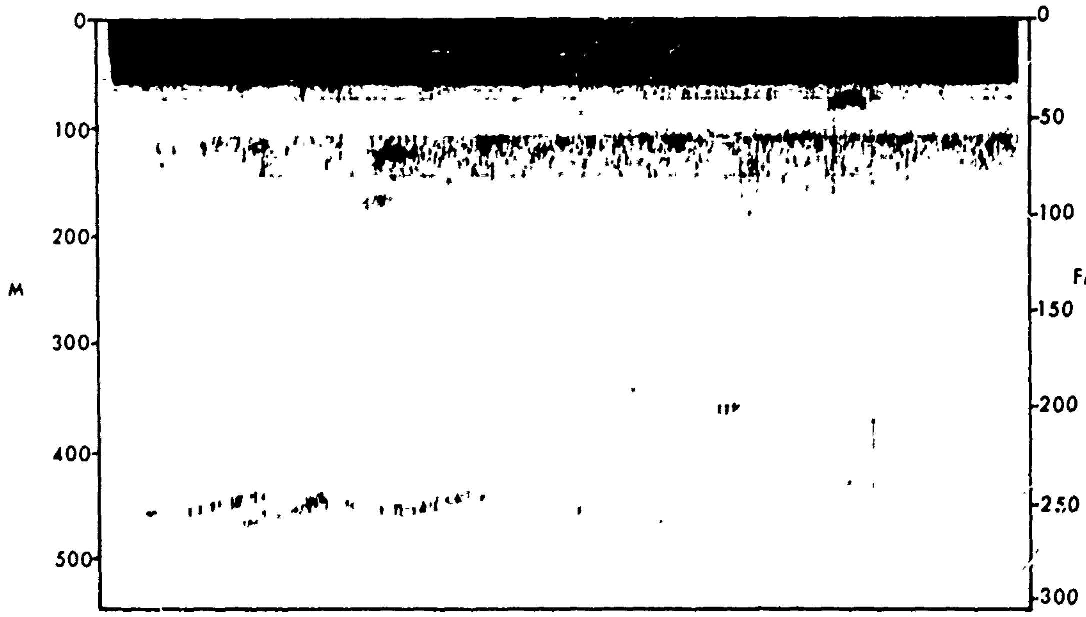
Area Station L
Time 0030-0255
Note The echo grams show the amplifying effect of scale changes 100 Fm scale Echo groups greatly manified and highly serrated due to the individual signals

Figure 25A. Recorder scale comparison.



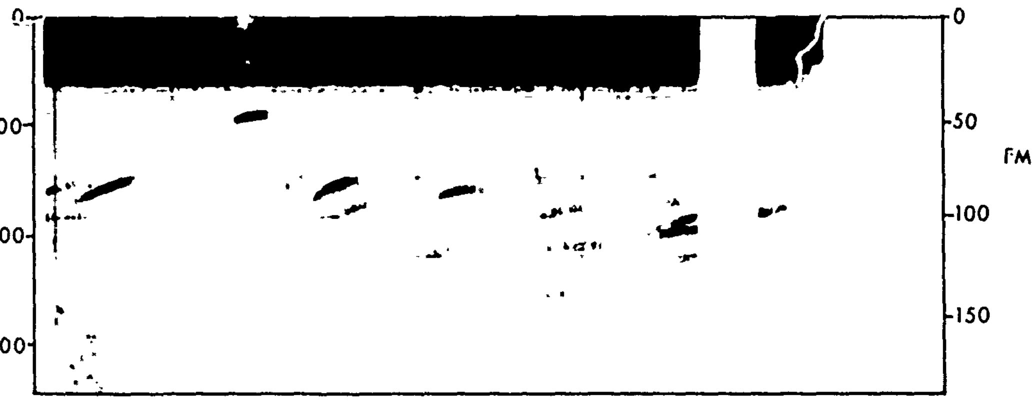
Area: Enroute Station M
Time: 0000-0055, 18 Apr
Note: Heavy concentration of small echo groups in the upper 200 m. (Approx. 0.5-0.6 echo groups/$10^6 m^3$).

26A. Night scattering.



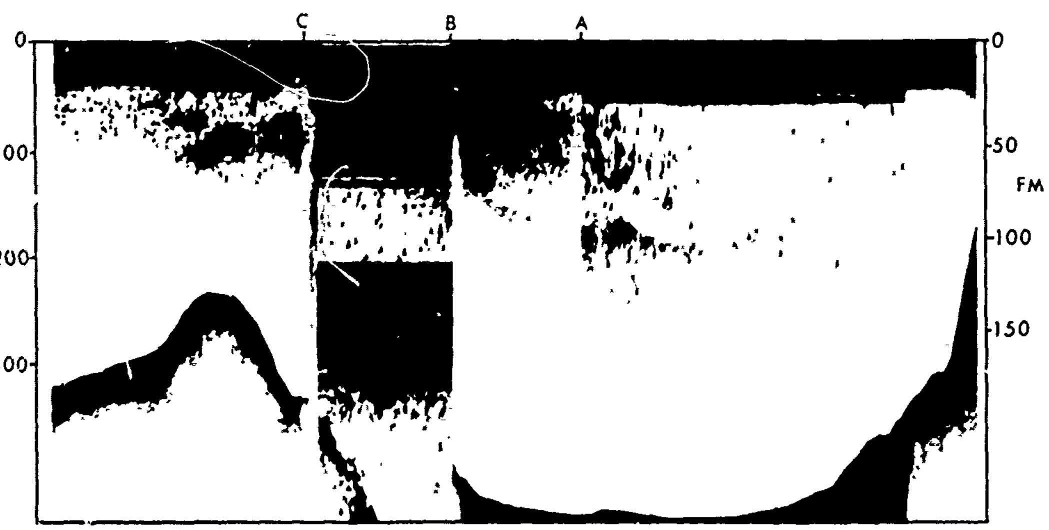
Area: Station M. (Sea of Japan)
Time: 1430-1520, 18 Apr.
Note: A few long serrated targets remain in the sound cone for 30 minutes or more at near 450 m.

27A. Day scattering.



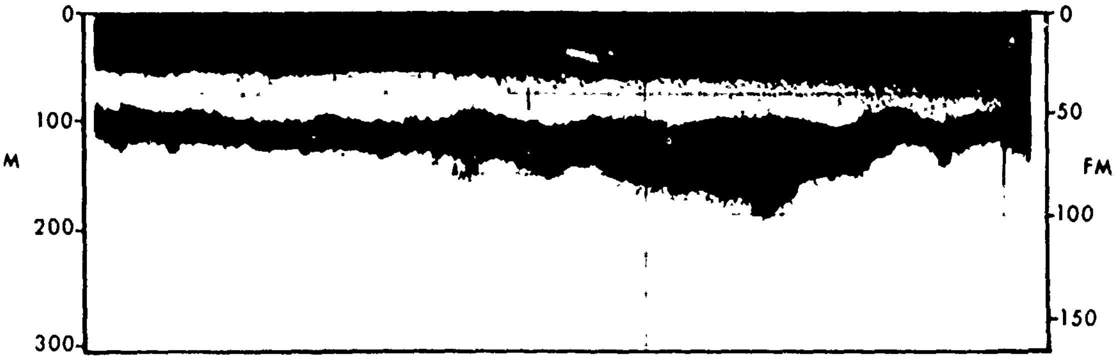
Area Station M
Time 1950-2045, 18 Apr.
Note Elongated serrated echo groups from 100 to 250 m; common for the Sea of Japan area

28A. Night scattering.



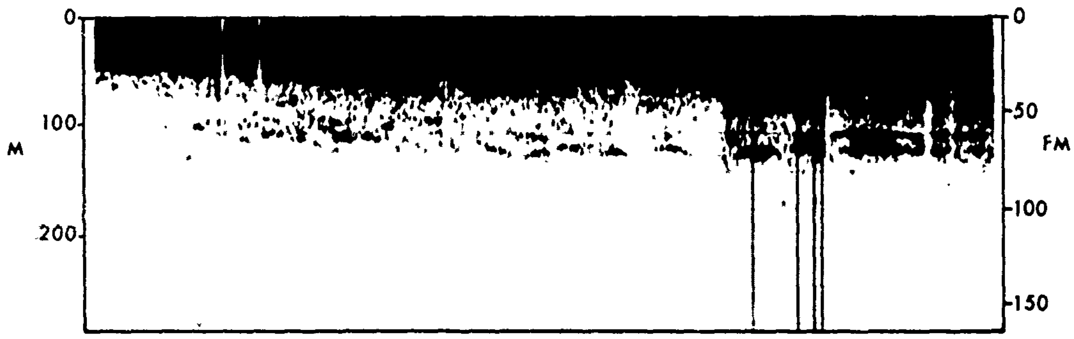
Area Enroute Sasebo
Time 0050-0140, 21 Apr
Note Moving from right to left Initially on the 400 Fm scale, with identifiable small echo groups At event A, individual SEGs nearly lost in cloud-like scattering, due to decrease in signal length At event B, scale changed to 100 Fm, distinct echo group pattern can be seen At event C, the scale is turned back to 400 Fm scale, targets become much smaller and less well defined

29A. Scale and signal length comparisons.



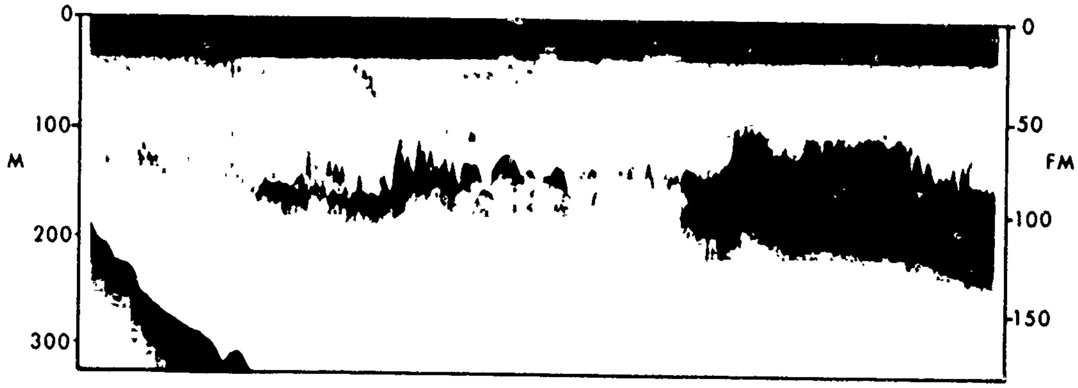
Area. Enroute Sasebo
Time· 1439·1535, 21 Apr
Note Extremely dense layer at 100 m. Possibly made up of very small echo groups similar to those in Figure 29A.

30A. Day scattering.



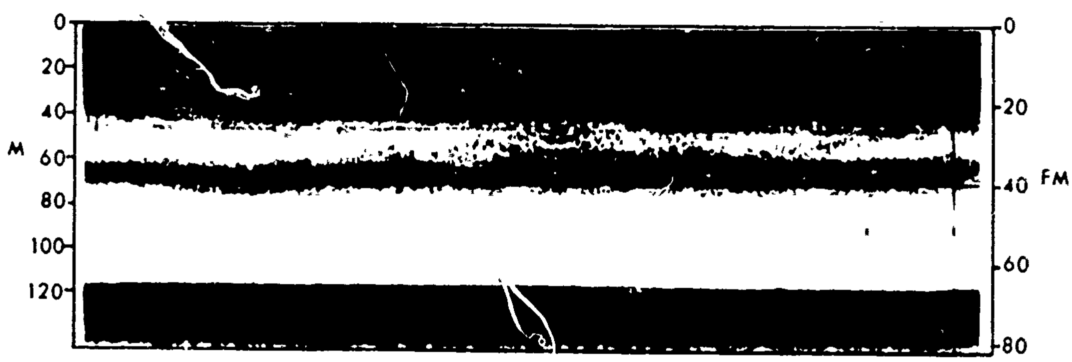
Area. Station N
Time· 1735-1830, 28 Apr.
Note Diffuse near surface scattering and MEGs to 130 m.

31A. Night scattering.



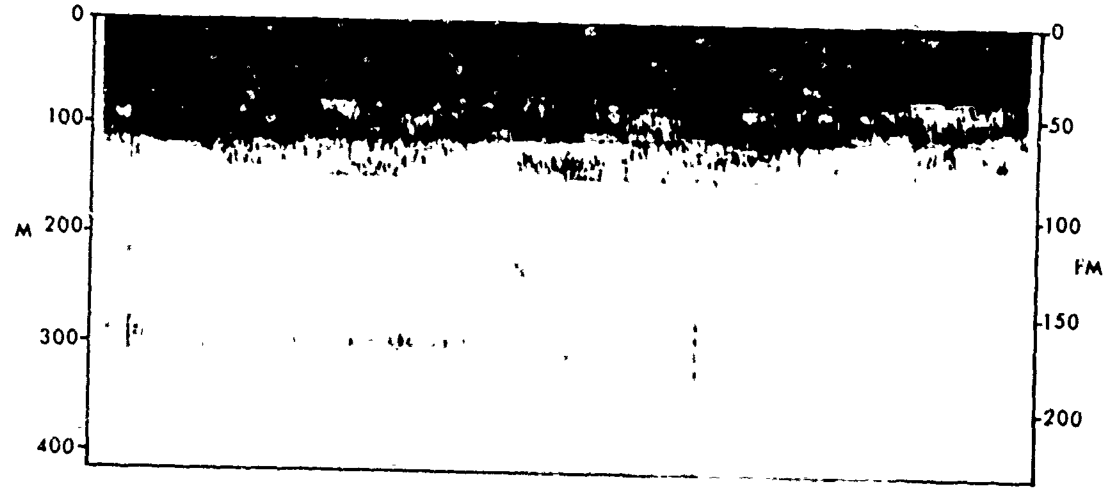
Area: Enroute Sasebo
Time 1045-1140, 29 Apr
Note MEG and LEG layer at 100 to 200 m Signal length and gain changes are shown to affect trace, clearly making the targets more discrete with decreased gain This layer of discrete targets near the Tsushima Strait is similar in size and depth to the MEG layer near the Tsugaru Straits off the East Coast of Japan.

32A. Day scattering.



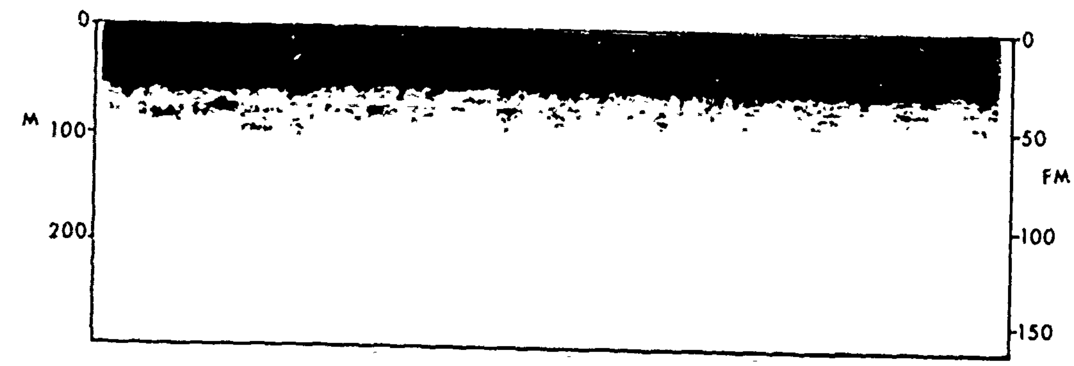
Area Station O (East China Sea)
Time 1304-1332, 1 May
Note Heavy scattering layer at 60 m, bottom at 120 m

33A. Day scattering.



Area Station P
Time 1605-1700, 4 May
Note Relatively dense near surface scattering to 120 m. Diffuse layer from 220 to 320 m

34A. Day scattering.

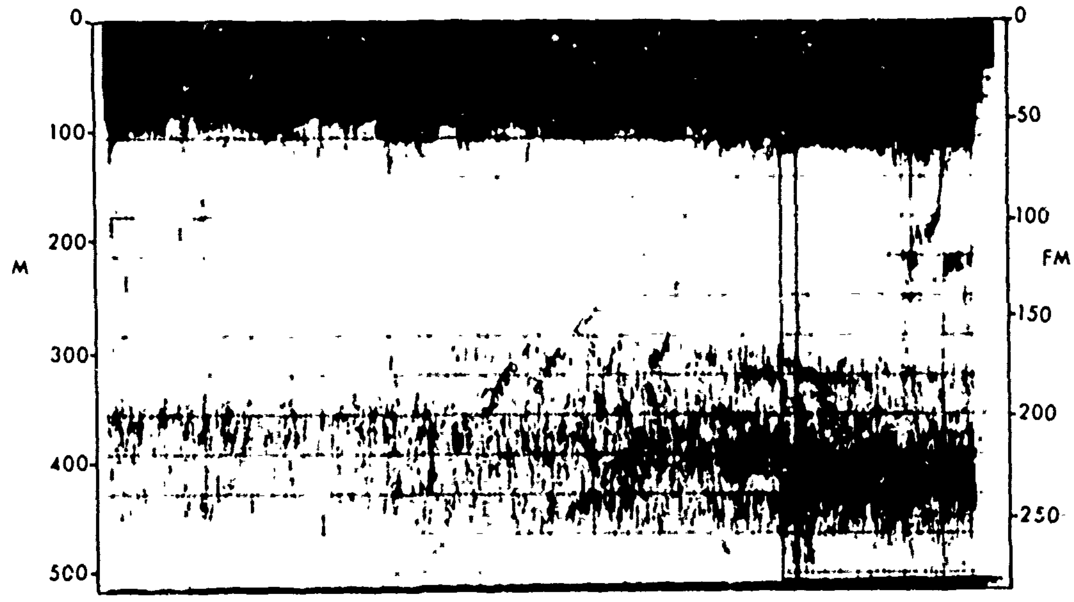


Area Station Q
Time 1240-1335, 11 May
Note Near surface scattering to 100 m, possibly made up of individual echo groups

35A. Day scattering.

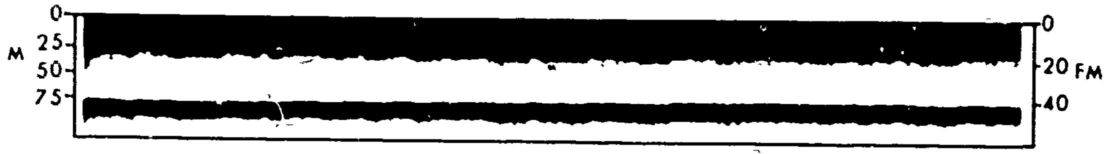
Area Station R (South China Sea)
Time 1130-1440, 13 May
Note Near surface small LEGs to 120 m Exceptionally large echo groups near 250 m, appear to be relatively common in this part of the South China Sea.

36A. Day scattering.



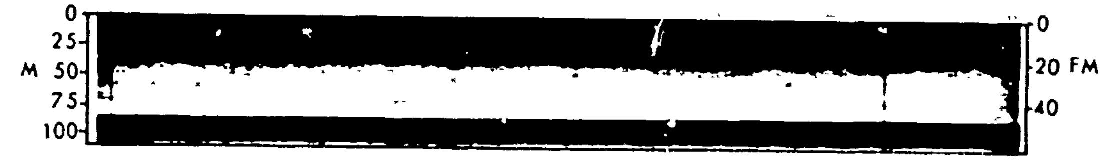
Area Station S
Time 1550-1650, 23 May
Note Heavy scattering between 300 and 450 m The extreme depth and density may be partially due to the high gain setting (8)

37A Day scattering



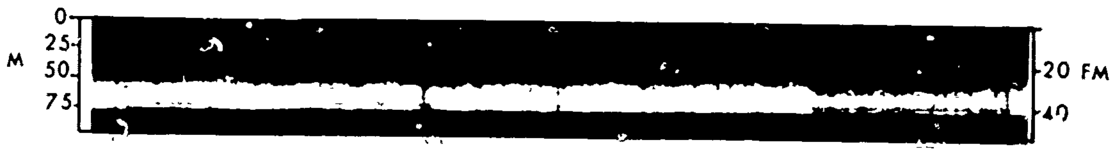
Area Station T
Time
Note Very shallow (bottom at 75 m) Slight diffuse scattering near surface

38A. Day scattering



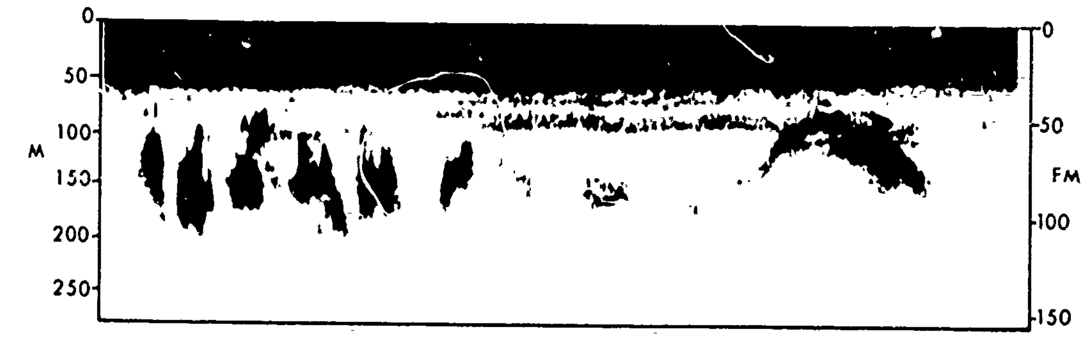
Area Station T
Time 0200-0255
Note Scattering appears to have dropped closer to the bottom (to 75 m)

39A. Night scattering



Area Station U
Time 2130-2225, 30 May
Note Again, shallow with apparent near surface scattering.

40A. Night scattering.



Area Enroute to Subic Bay P I
Time 1535-1630, 3 Jun
Note Very large echo groups similar to those seen on Sta R are observed to 200 m Surface scattering to 100 m

41A. Day scattering.

APPENDIX B: CHECKLIST OF FASOR II FISHES

This Appendix summarizes the total number and size range of fish collected for each haul on station during FASOR II operations.

FAMILY MYCTOPHIDAE: Lanternfishes

Ceratoscopelus warmingi

Diaphus effulgens
D. garmani
D. mollis
D. theta
D. sp.

Lampanyctus guentheri
L. jordani
L. punctatissimus
L. ritteri
L. tenuiformis

Notoscopelus hoffmanni

Stenobrachius leucopsarus

Tarletonbeania crenularis

FAMILY GONOSTOMATIDAE: Lightfishes

Gonostoma gracile

Vinciguerria nimbaria
V. sp.

FAMILY BATHYLAGIDAE: Blacksmelts

Bathylagus ochotensis

Leuroglossus stilbius

Larva

FAMILY IDIACANTHIDAE: Blackdragons

Idiacanthus antrostomus

FAMILY STERNOPTYCHIDAE: Hatchetfishes

Argyropelecus lychnus

FAMILY MELANOSTOMIATIDAE: Scaleless Dragonfishes

Opostomias sp.

Tactostoma macropus

FAMILY EXOCOETIDAE: Flying Fish

Exocoetus vinciguerre

FAMILY INDEFINITE

Juvenile Fishes

Leptocephalus Larvae

Miscellaneous Larvae

FAMILY SCOPELARCHIDAE: Pearleyes

Neoscopelarchoides dentatus

Larva

FAMILY STOMIATIDAE: Scaly Dragonfishes

Stomias affinis

S. sp.

The number and site of generic and specific representatives for haul and station.

Station	Haul	Family (common name)	Genus & Species	No.	Size Range (mm)
ASH	1	MYCTOPHIDAE	*Diaphus* sp.	2	47,70
			Lampanyctus guentheri	1	33
			L. jordani	2	37,45
			L. ritteri		
		IDIACANTHIDAE	*Idiacanthus antrostomus*	1	200
		STERNOPTYCHIDAE	*Argyropelecus lychnus*	2	22,26
		MELANOSTOMIATIDAE	*Opostomias* sp.	1	95
			Tactostoma macropus	1	179
BEECH	3	MYCTOPHIDAE	*Diaphus theta*	4	44-80
			Stenobrachius leucopsaurus	13	21-80
			Tarletonbeania crenularis	2	32,35
		BATHYLAGIDAE	*Bathylagus ochotensis*	1	78
		Indefinite	Miscellaneous Larvae	4	--
CEDAR	5	MYCTOPHIDAE	*Diaphus theta*	8	48-74
			Stenobrachius leucopsaurus	71	21-65
			Tarletonbeania crenularis	2	26,31
DATE	8	MYCTOPHIDAE	*Stenobrachius leucopsaurus*	3	63-69
		BATHYLAGIDAE	*Leuroglossus stilbius*	1	44
			Bathylagid Larva	1	--
ELM	9	MYCTOPHIDAE	*Stenobrachius leucopsaurus*	1	69
HOLLY	12	BATHYLAGIDAE	*Leuroglossus stilbius*	1	128
IVY	13	Indefinite	Juvenile Fish	1	--
IVY	14	MYCTOPHIDAE	*Diaphus theta*	1	74
			Lampanyctus jordani	1	56
		GONOSTOMATIDAE	*Gonostoma gracile*	3	62-71
		Indefinite	Larva	1	--

Station	Haul	Family (common name)	Genus & Species	No.	Size Range (mm)
IVY	15	Myctophidae (lantern fishes)	*Diaphus theta*	67	37-82
			Stenobrachius leucopsarus	2	24,68
		Gonostomatidae (light fishes)	*Gonostoma gracile*	10	59-85
		Bathylagidae (deep sea smelts)	*Bathylagus ochotensis*	11	--
		Scopelarchidae (pearleyes)	*Neoscopelarchoides dentatus*	1	75
			Larva	1	--
JUNIPER	17	Indefinite	Miscellaneous Larvae	4	--
KALMIA	18	Indefinite	Juvenile Fish	1	--
KALMIA	19	Indefinite	Larva	1	--
LEMON	21	Indefinite	Juvenile Fish	1	--
NUTMEG	25	Indefinite	Juvenile Fish	1	--
PLUM	27	Indefinite	Miscellaneous Larvae	8	--
PLUM	28	MYCTOPHIDAE	*Ceratoscopelus warmingi*	5	21-79
			Diaphus effulgens	3	35-50
			Lampanyctus tenuiformis	4	35-52
			Notoscopelus hoffmanni	2	35,40
		GONOSTOMATIDAE	*Gonostoma gracile*	4	28-33
			Vinciguerria nimbaria	4	22-30
		STOMIATIDAE	*Stomias* sp.	1	25
		Indefinite	Juvenile Fish	1	--
			Leptocephalus Larvae	2	--

Station	Haul	Family (common name)	Genus & Species	No.	Size Range (mm)
QUINCE	29	Indefinite	Miscellaneous Larvae	55	--
REDWOOD	30	Indefinite	Miscellaneous Larvae	14	--
SPRUCE	32	Indefinite	Miscellaneous Larvae	12	--
SPRUCE	33	MYCTOPHIDAE	*Ceratoscopelus warmingi*	5	27–42
			Diaphus garmani	1	35
			D. mollis	2	27,49
			Lampanyctus punctatissimus	1	44
			L. tenuiformis	1	32
			Notoscopelus hoffmanni	1	49
		GONOSTOMATIDAE	*Vinciguerria* sp.	1	--
		STOMIATIDAE	*Stomias affinis*	2	49,51
		EXOCOETIDAE (flying fish & half beaks)	*Exocoetus vinciguerre*	1	89
		Indefinite	Juvenile Fishes	3	--
			Leptocephalus Larvae	16	--
THORN	36	Indefinite	Juvenile Fishes	36	--
			Miscellaneous Larvae	14	--
UPAS	37	Indefinite	Juvenile Fishes	5	--
UPAS	38	Indefinite	Miscellaneous Larvae	65	--